GEK MEASUREMENTS OF SURFACE CURRENTS IN MONTEREY BAY 1971

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THESIS

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of
Surface Currents in Monterey Bay
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by

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ABSTRACT

Utilizing the geomagnetic electrokinetograph (GEK), surface currents in Monterey Bay were determined for five distinct cruises, each in a different portion of the bay, during the period November to December 1971. These cruises, using the Naval Postgraduate School (NPS) research vessel R/V Acania, yielded a total of 90 current speeds ranging from a low of 2.56 cm/sec to a high of 58.16 cm/sec. The direction of the current vectors were compared with currents inferred from the 10°C and 12°C mean isothermal surfaces. The isothermal surface data used was both of a historical and synoptic nature, the latter being obtained during the November-December 1971 time frame.

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I. INTRODUCTION

A. REVIEW

The electromagnetic principle provides a means for continuous observations from a moving platform of surface current velocities in the open ocean. Since sea water is in fact an electrolyte and contains a large quantity of dissociated salts, the motion of salt water through the earth's quasi-static magnetic field produces a gradient of electric potential which can be recorded and analyzed, yielding surface current velocities.

The measurement of surface currents utilizing electromagnetic principles was attempted by Michael Faraday in 1832 on the Thames, but the use of copper electrodes degraded his results because they developed their own chemical potentials. Succeeding investigations were undertaken by Longuet-Higgins and Barber (1946), von Arx (1950), and others. Hughes (1962) investigated the towing of electrodes in shallow water, and more recently, Sanford (1967) considered the velocity and electric fields from a three-dimensional standpoint.

The development of the geomagnetic electrokinetograph (GEK) during the years 1946-1950 at the Woods Hole Oceanographic Institution made possible the routine determination of ocean surface currents from a ship while underway.

B. OBJECTIVES

The essential equipment that is required for surface current measurement utilizing the GEK are: (1) a pair of electrodes normally separated by a distance of 100 m, mounted on a two-conductor cable which must be long enough to isolate the electrodes from the influences of the ship, and (2) a recording potentiometer on board the ship. The concept behind this towing method is that the measurement of the horizontal electrical potential gradient in the ocean, by the movement of electrodes through the water, can be interpreted as a current velocity.

The present investigation was undertaken not to propose or to prove a new thesis but rather to expand on the work of McKay (1970) and to determine the surface currents in Monterey Bay for the short period, November-December 1971, utilizing a neutrally buoyant cable. Emphasis on current speed and direction were of principal interest with a secondary goal of comparing current vectors with the inferred currents of the mean isothermal surfaces for the months studied.

The general outline of the area studied along with the position of current vectors may be seen in Fig. 1, while the current vectors themselves are shown in Fig. 7a through 12.

Five cruises were conducted utilizing the Naval Postgraduate vessel R/V ACANIA. Each cruise will be considered separately in detail.

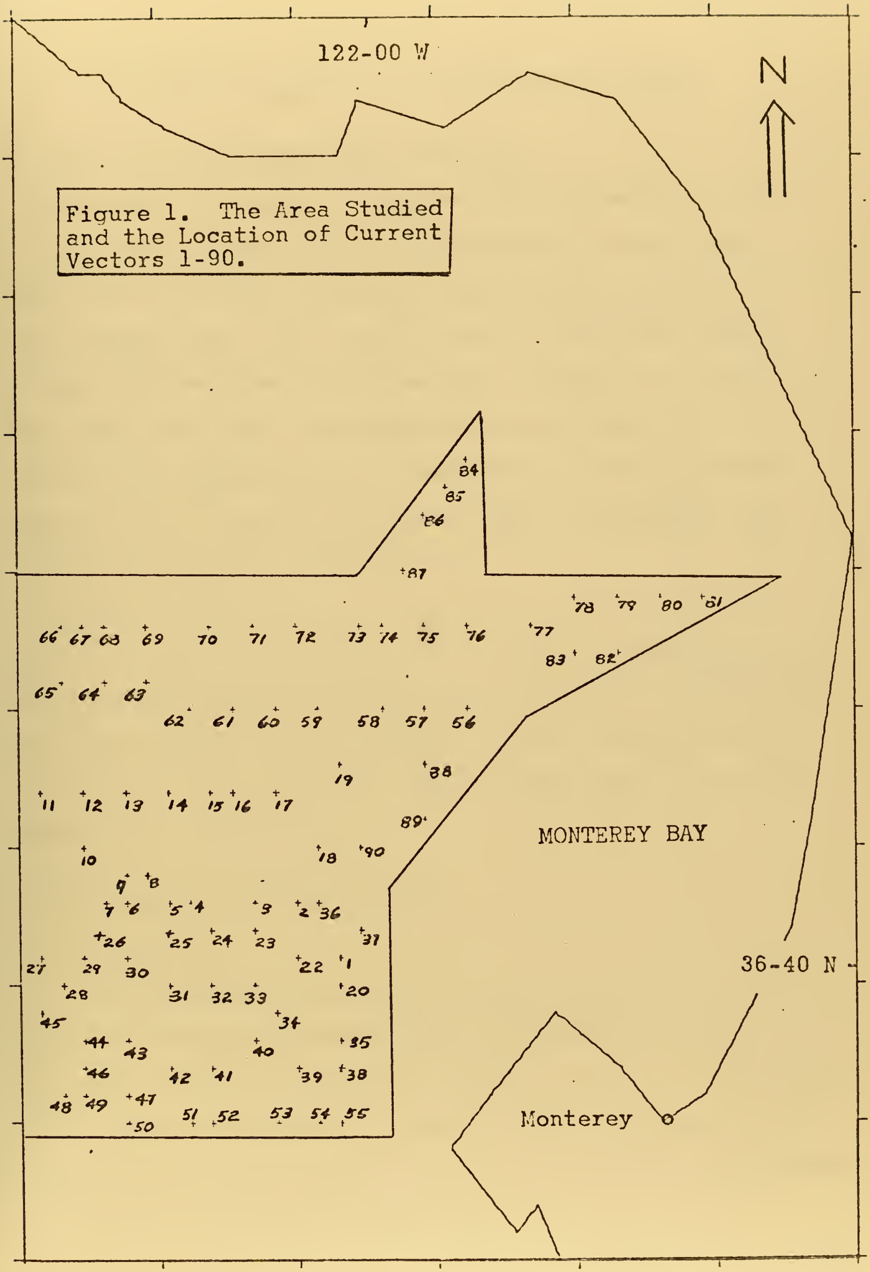


Figure 1. The Area Studied and the Location of Current Vectors 1-90.

II. PHYSICAL PRINCIPLES OF THE ELECTROMAGNETIC METHOD

A. THEORY OF THE ELECTRICAL FIELD IN THE SEA

The movement of sea water through the motionless magnetic field of the earth induces electric potential gradients and electric currents. These effects can be best described by the classical relationships of electromagnetic theory. The electric potential field can be deduced by applying Faraday's Law of Electromagnetic Induction to a closed curve fixed in the fluid. We assume that the resistivity of sea water fluctuates only slightly with depth and position and that the earth's magnetic field is uniform over the area studied. The gradient of the electric scalar potential, $\nabla\phi$, is given by

$$\nabla\phi = (\bar{V} \times \bar{H}) - \rho\bar{i} \qquad (1)$$

where $\bar{V}$ is the fluid velocity vector, $\bar{H}$ is the magnetic field intensity, ρ is the scalar electrical resistivity of the fluid, and $\bar{i}$ is the electric current density along the conductor. A more elaborate discussion can be found by consulting von Arx (1950), Longuet-Higgins, Stern, and Stommel (1954), or Curtin (1970).

B. THE GEOMAGNETIC ELECTROKINETOGRAPH

1. Description

The GEK method of measuring the voltage expressed in equation (1) consists of towing two electrodes astern on an insulated two-conductor cable with a shipboard-installed high impedance voltmeter. This voltmeter is of the recording potentiometric type consisting of a balanced bridge designed with high input impedance, thus restricting the electrical current from flowing in the measuring circuit (Fig. 2).

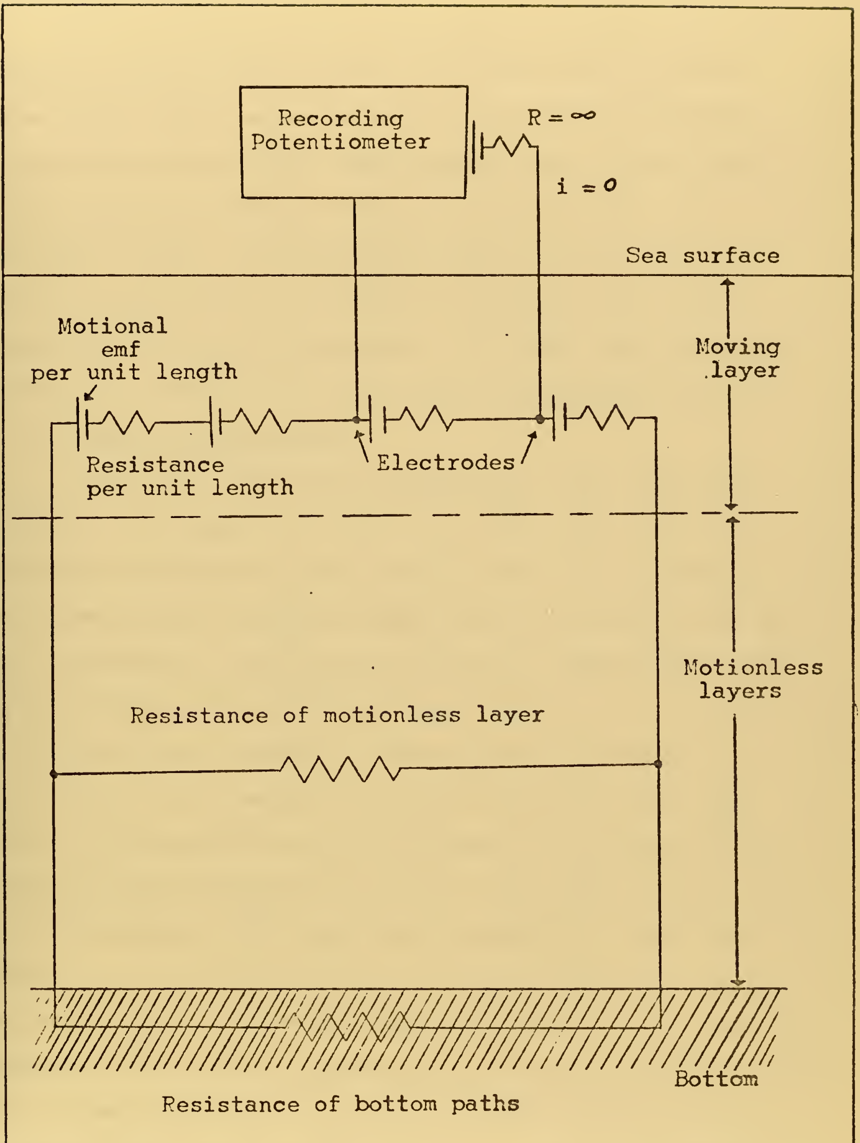


Figure 2. Equivalent Circuit of Electromagnetic Method.

The electrodes used in GEK measurements are almost exclusively of the silver-silver chloride type. The two electrodes are matched so as to have exactly the same contact potential from the metal wire to the sea-water electrolyte. Their opposing battery effects in the circuit cancel out and thus no chemical potential results. The electrodes are towed a few ship lengths behind the vessel so as to preclude the possibility of recording in the region of the earth's magnetic field disturbed by the passage of the steel hull. The standard interelectrode distance is 100 m for silver-silver chloride electrodes.

2. Theory of GEK Operation

Two separate moving conduction paths are present when towing electrodes in sea water: (1) ocean water itself, and (2) the two conductor cable contained in the measuring circuit. The potential in each of these paths is the difference between the two terms $(\bar{V} \times \bar{H})$ and $(\rho\bar{i})$ of equation (1). The following discussion is taken directly from the development by Curtin (1970) and McKay (1970).

Consider the sea water path. When electrodes are towed, as shown in Fig. 3, they measure the potential difference along a path parallel to the direction of the ship's heading. The component of emf generated in this direction by the $(\bar{V} \times \bar{H})$ term is $(V_yH_z - V_zH_y)$, where V_y is the component of the water velocity perpendicular to the course steered, V_z is the vertical component of the water velocity, H_z is the vertical intensity of the earth's magnetic field and H_y is the horizontal geomagnetic field intensity perpendicular to the course steered. The term V_z is assumed to be zero at the surface and at the bottom of the sea and is probably small even in zones of sinking and upwelling. Therefore, the emf contributed by the $(\bar{V} \times \bar{H})$ term parallel to the ship's course is V_yH_z and is due to the component of water velocity perpendicular to the ship's

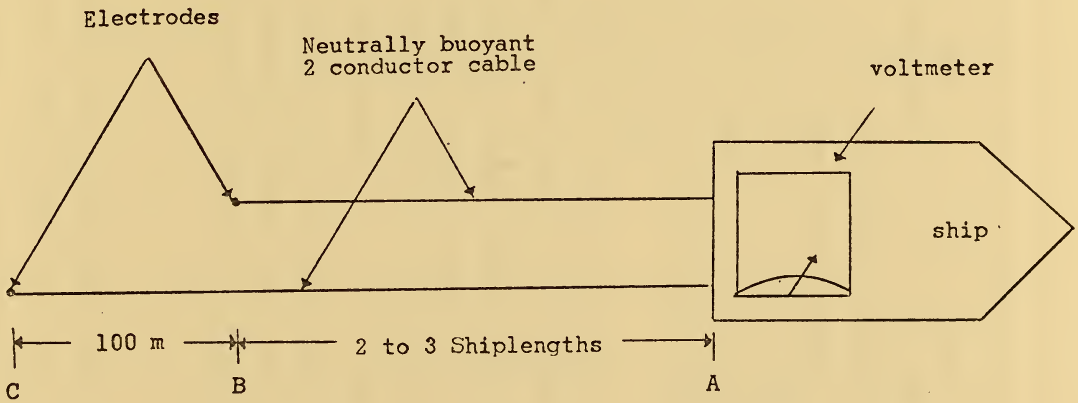


Figure 3. GEK
Component Arrangement

heading. The second emf in the sea water path, $\rho\bar{i}$, is a direct result of the electrical current density along the path between the electrodes. This electric current density depends on the emfs and the resistances of all the other surrounding paths since it is through these paths that a closed electrical-current-carrying circuit can be formed.

Now consider the closed conducting path formed by the tow wires, the sea water between the electrodes, and the voltmeter. It can be shown by reasoning identical to that used for the sea water path that the velocity induced emf per unit distance contributed by the $(\bar{V} \times \bar{H})$ term in equation (1) is $V_y H_z$. Due to the high impedance of the voltmeter, $\rho\bar{i}$ is essentially zero in this path.

The potential differences developed in the wires to each electrode and the potential in the sea water between the electrodes are continuously recorded by the voltmeter. Following the path as shown in Fig. 3 and adding the potentials yields the following results:

$$E=(V_y H_z)_{AB} + (V_y H_z)_{BC} + [(-V_y H_z)_{CB} - (\rho\bar{i}_x)_{CB}] + (-V_y H_z)_{BA} \qquad (2)$$

where E is the emf per unit distance, and A, B, and C are the points as shown in Fig. 3. The term enclosed in squared brackets is the potential gradient between the electrodes in sea water, while the induced emf in the indicated sections of the wire compose the remaining terms. Equation (2) reduces to

$$E=(-\rho\bar{i}_x)_{CB} \qquad (3)$$

where the direction would be that of a line drawn between the two electrodes, or in the case of the electrodes towed directly astern, the direction of the ship's heading. The quantity measured by the voltmeter becomes

$$E(\text{Volts}) = [\ K\int_C^B - \rho i_x dx\ ] \times 10^{-8} \qquad (4)$$

where 10^{-8} is the proportionality factor between electromagnetic cgs units and practical units (10^{8} electromagnetic cgs units = 1 v). The "K" factor, a dimesionless ratio, will be discussed in greater detail in Sec. II-B-4.

3. Current Direction Determination

In determining currents in the deep ocean it is assumed that the potential gradient is completely short-circuited by the deep layer of relatively still water underlying the surface layer. This assumption yields the case where $\nabla\phi=0$ and $\rho\bar{I} = \bar{V} \times \bar{H}$. Using the symbol s to indicate the interelectrode distance, the horizontal potential difference measured by the voltmeter is

$$E(\text{Volts}) = (KsH_zV_h) \times 10^{-8} \qquad (5)$$

where V_h is the horizontal component of water motion perpendicular to the interelectrode line, and H_z is the intensity of the vertical component of the earth's magnetic field in oersteds. If V_h is positive toward the east, H_z is directed downward, and s is parallel with a meridian of longitude, then E will have positive polarity at the south end of s and negative at the north end.

Since the vertical component of the earth's magnetic field (H_z) is directed downward in the northern magnetic hemisphere, the direction of water motion lies 90° to the right of the positive sense of the horizontal component of the electric vector. In the southern magnetic hemisphere the vertical component of magnetic flux is directed upward so that the water motion vector lies 90° to the left of the horizontal electric vector. With these principles in mind the cable connections to the recorder should be made according to the following convention for the northern magnetic hemisphere - the conductor leading to the

more distant electrode is connected to the voltmeter input terminal which when made positive gives a right-hand deflection of the recorder pen. This convention allows the observer facing the recorder to see the pen on the same side of zero as the direction toward which the ship is being set. The connections must be reversed in the southern magnetic hemisphere to have the same convention apply.

4. The K-Factor

The results of most experiments which compare the current speed as observed by use of the GEK with the current speed observed by use of non-electromagnetic means are expressed in terms of a ratio E' /E where E' is the voltage calculated from the non-electromagnetic water speed ($E' = sH_zV_h \times 10^{-8}$ v) and E is as given in equation (5). This ratio is the so-called K-factor. If the assumptions made for deep sea currents were entirely satisfied the K-factor would be unity. As might be expected, such conditions rarely exist. Von Arx (1950) cites the following typical K values - in very shoal tidal reaches of less than 10 m depth the K-factor may vary from station to station within the range of 1.5 to 15.0 with an average near 10.0 on the continental shelf in depths of 10 to 100 m the K-factor averages less than 2.0 and seldom exceeds 3.0 in individual cases, beyond the 150 m isobath the K-factor is predominately less than 1.10, the average open ocean value being 1.04. The U. S. Naval Oceanographic Office in its publication, H. O. PUB. 607 (1970) utilizes a K-factor of 1.04 in all depths although it seems likely that this is a matter of convenience for unskilled operators who have no knowledge of the theory involved, rather than a scientific certainty.

It would seem that the value of the K-factor is solely dependent on depth; however, this is not entirely true. In areas where tidal currents are predominant and the flow is more or less uniform to the bottom, bottom sediments provide the principal short circuiting medium. Since the electrical resistance of bottom sediments is higher than that of sea water, the resulting K-factor will be larger. In some regions of the continental shelf oceanic circulation reaches inward over the shelf and wind driven layers become important. In this case shear is introduced causing a reduction in the value of K. The K-factor will vary considerably, with both time and position, in shallow water since both shear and turbulence are present.

Comparison studies of current vectors from GEK data and those computed by other means were reported by von Arx (1950). It may be inferred from these comparisons that if one knows nothing at all about the expected value of K and therefore assumes a value of from 1.0 to 1.10 the average error would be less than 10%. After many comparisons von Arx concluded that if the deep water average of 1.04 was used the error would be reduced to the order of 5%.

Since no research in Monterey Bay has ever been done to determine a K-factor, a decision had to be made as to an appropriate value. The selection of a K-factor does not in any way effect the direction of the current vector as determined from GEK data. It does, however, effect the magnitude of the resultant current vector. Drogue tracking, as a method of determining current velocity, was rejected due to tracking limitations of the R/V ACANIA's radar and the implimentation of current meters was not considered feasible due to the large number of observations at various depths that would be required.

Considering these factors led to the choice of a K value of 1.04 for this study.

5. Cable Droop

Long cables that are more dense than sea water introduce a vertical component of length z - the vertical separation between the electrodes. This component cuts the horizontal component of the earth's magnetic field H_h producing a signal proportional to $H_h(zv\sin\theta) \times 10^{-8}v$, where v is the speed of the ship and θ is the magnetic azimuth of the course steered. Since the horizontal component of the magnetic flux has a fixed azimuth, the result confuses observations by adding a spurious signal which can be interpreted as a component of current velocity toward magnetic south in the northern magnetic hemisphere, and the magnetic north in the southern magnetic hemisphere. This effect is strongest within 30° of the earth's magnetic equator. This problem is generally eliminated through the use of a neutrally buoyant cable which allows the cable to be towed on or near the sea surface.

6. Wind Deflection of the Cable

When a neutrally buoyant cable is used it is subject to a transverse force exerted by the wind. Wind will drift the ship and/or cause the electrodes not to tow directly astern. The direction of the interelectrode length differs from the steered heading by arctan D/v where D is the rate of lateral drift due to windage, and v is the ship's speed through the water in the direction steered. Thus, wind drift is observed in combination with the measured current principally as a small error in direction.

The cable used during the course of this study was of the neutrally buoyant type, however, since data was recorded only during periods of negligible wind this potential source of error was eliminated.

C. INTERPRETATION OF DATA

1. General

The electrical current density $\bar{I}$ in any region is a function of the conducting path in which it exists. Thus, in the ocean, with the assumption of uniform resistivity, the current density integrated along any line is directly dependent on the emfs produced in the available sea water paths surrounding that line. These emfs, as shown in equation (1), are directly related to the velocity of the water in that region. Thus, the velocity field in the entire water column below the surface is reflected, in part, by any electrical current density measured at the surface.

In the interpretation of GEK data it is important, in the absences of information derived from other sources to keep the following assumptions in mind as defined by McKay (1970):

(a) the vertical component of water velocity is negligible in comparison with the horizontal component,

(b) the flow is broad compared with the depth of the water,

(c) the current is steady in the horizontal,

(d) the depth-averaged velocity is essentially zero in comparison with the surface velocity,

(e) a deep layer of still water underlies the moving surface layer, and

(f) the effect of a conducting sea bottom can be considered negligible in depths greater than 70 fathoms.

There is one further source of emf in the measuring circuit. This is the self-potential of the electrodes due to the fact that they are metals immersed in an electrolyte. This electrode phenomenon is discussed in Sec. III-C.

2. <u>Accuracy Estimation</u>

Utilizing the GEK Model V recording potentiometer and strip chart recorder (as designated by the Naval Oceanographic Office), the trace can easily be read to an accuracy of ± 1 cm/sec and, since two readings in opposite directions are taken and averaged for each current fix, this inaccuracy contributes little or nothing to the over-all error.

As mentioned in Sec. II-B-5 and II-B-6 the effects of cable droop were eliminated by the use of a neutrally buoyant cable and wind defection of the cable was negligible since data collection occurred during low wind conditions.

The actual data reduction was carried out utilizing the NPS IBM-360/67 computer and the initial vector calculations were compared by hand to insure the validity of the program (a copy of the program is to be found in the Appendix).

Using a K-factor of 1.04, as discussed in Sec. II-B-4, reduced thus source of error to the order of 5%.

A consideration of all these factors led to the following estimate of accuracy:

<u>current speed</u>: ±5% of calculated speed

<u>current direction</u>: ±5%

III. EQUIPMENT USED

A. RECORDING POTENTIOMETER AND STRIP CHART RECORDER

The recorder is calibrated to read current speed directly in either centimeters per second or knots. Assuming the cable connections are made as suggested in Sec. II-B-3 a port set is indicated by deflection to the left of center scale and starboard set by deflection to the right. An excellent view of the recorder can be seen in H. O. Pub. 607 (1970) along with an adequate discussion of all the control functions. A sample recorder output is shown in Fig. 4.

The sensitivity of the system is so arranged that the nominal signal (equation (5)) for significant water motion (1 cm/sec) is above the threshold of recorder response and is large in comparison with the electrochemical drift of potential of the electrodes. This sensitivity is established by setting the value of H_z on the vertical intensity knob which is calibrated in oersteds. The value of H_z can be calculated from the information taken from H. O. Chart No. 1702 - The Vertical Intensity of the Earth's Magnetic Force. Since the exact local value of H_z can not be set on the sensitivity control, a magnetic multiplier must be utilized. The value of the multiplier is obtained by taking the ratio of the nearest standard value of the magnetic vertical intensity to the local value of the magnetic vertical intensity as obtained from the chart. In this case the multiplier 0.913 (0.400 oersted/0.437 oersted) was used.

In order to block any possible direct current that may be present on the ship's service lines it is necessary to isolate the power to the recorder by means of an isolation transformer. Also, a spurious AC signal introduced in the ship's ground may result in deflecting the recorder pen

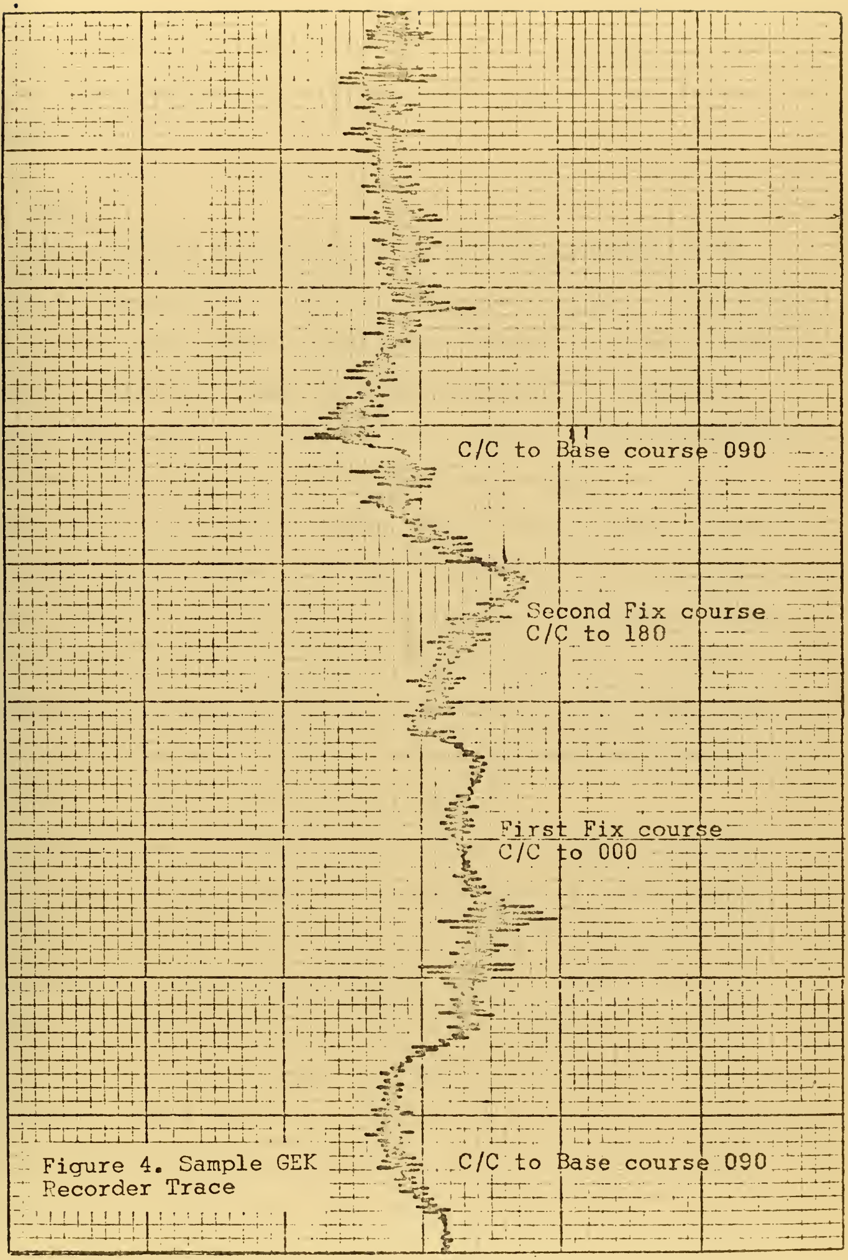


Figure 4. Sample GEK Recorder Trace

into either the port or starboard stops. Use of a conventional two-prong, rather than a grounded three-prong plug will entirely eliminate this problem.

B. CABLE

The function of the GEK cable is to allow the electrodes to be towed far enough astern so that the signal generated will be unaffected by the ship itself and by its disturbing influence on the sea. Normally anywhere from 1.5 to 3 times the length of the ship is necessary to achieve this result. As discussed in Sec. II-B-5, long cables that are more dense than sea water introduce a vertical component of length which can cut the horizontal component of the earth's magnetic field and produce a spurious signal which must be accounted for by calculating a droop correction. To overcome this problem, 330 m of neutrally buoyant cable B-3088 were purchased from the Vector Cable Company. This is a two-conductor shielded cable with an outer covering of neoprene. One electrode was soldered to each wire of the two-conductors at a spacing of 100 m - a standard interelectrode distance.

The cable was towed astern of the 126-ft NPS research vessel the R/V ACANIA. Although cables of the type used have a normal breaking strength of 1000 lb or more, a 1/4-inch diameter polypropalene line was taped to the cable along the entire length to absorb most of the strain. The cable was then led over the stern through a snatchblock suspended from the upper rail. The cable was wound on a small reel which in turn was lashed to the deck. The reel was equipped with a crank which allowed the cable to be payed out while the ship was in motion and retrieved in the same manner. All data was obtained while cruising at an average speed of 4 knots, not due to any limitation of the ship or GEK equipment, but in order to record a greater density of current fixes.

C. ELECTRODES

In order for the GEK to function properly it is imperative that the electrodes make good electrical contact with the sea. Even in still water, the metal-electrolyte junction of an electrode and the sea water results in a contact potential. This potential will be zero if two electrodes are matched and connected so as to oppose each other in the circuit. The present state of the art makes it impossible to achieve this perfect match. An additional complication arises in that the contact potential is a function of sea water temperature, salinity, and pressure and the rates of flushing and aeration.

In this study the electrodes were of the silver-silver chloride type. Supplied by the Woods Hole Oceanographic Institution they are one of several common non-polarizing designs using a metal-halide. Their inherent insolubility is augmented by the common-ion effect in sea water. This, along with a low electrical resistance, makes them best suited for use at sea with the GEK. These electrodes use as raw ingredients chemically pure silver oxide and pure silver chloride powder. Combining these ingredients with distilled water, the paste that is formed is applied to either a silver or platinum wire gauze. After two applications the gauze is fired in a laboratory furnace. The resulting electrodes are ready to be matched and soldered to a cable.

The thickness of the silver halide coatings influence the contact potentials, thus, the potential difference between the two electrodes can be altered to some extent. It is therefore necessary to determine periodically the zero point of the electrical measurements which, of course, would be an emf recorded in the absence of a current component perpendicular to the interelectrode line. This potential can be determined by

reversing the ship's head thereby reversing the positions of the electrodes. The difference between the motional emf and the electrochemical potential are measured on the first fix course and again on the second fix course. The average of the two signals is taken as the value of electrical zero. During current computations this value is subtracted out so as to eliminate the electrochemical potential from the determination of the actual current vectors. Of course, the assumption must be made that the salinity, temperature, and pressure of the sea water along the tracks has not changed between the first fixed course and the second fixed course.

To increase electrode stability the electrode junctions were wrapped alternately with three layers of Scotchkote electrical coating and Scotch rubber tape followed by a good seal of rubber cement. The electrodes were then padded with glass wool and housed in a 1-ft section of plastic core tube. It is necessary to drill several small holes in the plastic tube to achieve sea water circulation; however, the pattern is arbitrary. The use of the glass wool and the plastic tube serves as a barrier to physical damage and as a means of controlling the electrode environment. Fig. 5 shows an example of the type of electrode housing used for this study. The aft end of the distant electrode was fitted with a manila line about 5 m long with a knot approximately every 3/4 m. The addition of this line assures straight and steady towing of the housing thus eliminating oscillations.

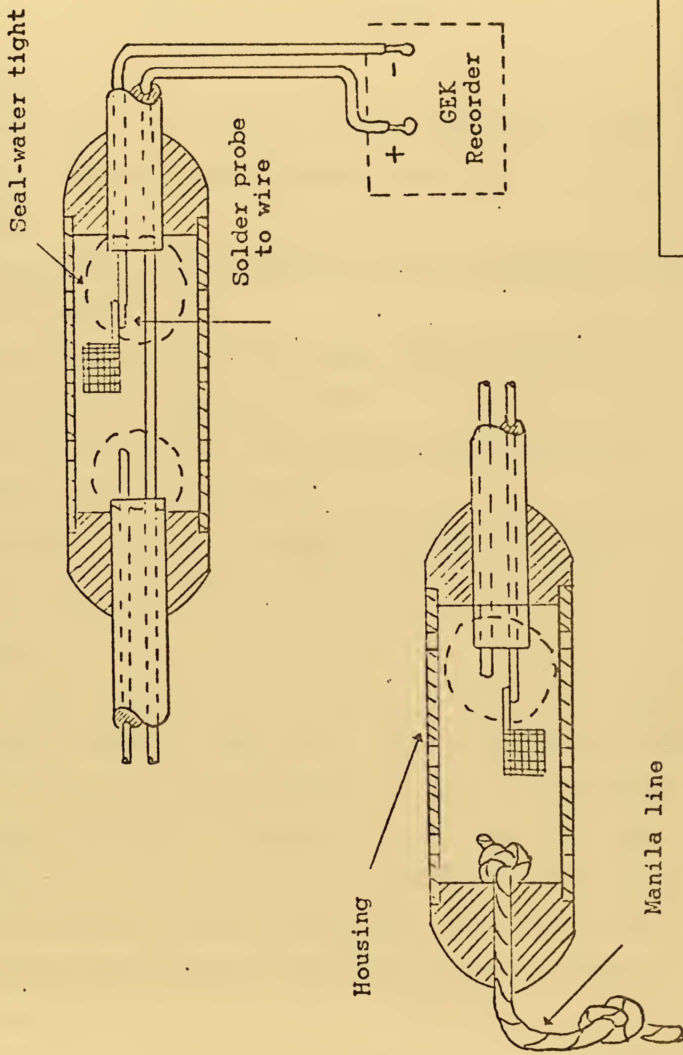


Figure 5. Electrode Housing

IV. CRUISE PLAN AND NAVIGATION

A. CRUISE PLAN

The track that the observing ship is called upon to steer for GEK observations is determined by the following requirements as stated by von Arx (1950):

(a) the potentials shall be measured on at least two headings at right angles if possible,

(b) at least once an hour the electrodes shall be reversed end for end to determine the "zero point ", and

(c) as little of the ship's time as possible shall be wasted in progressing toward her destination.

Using the above criteria the sailing plan, as shown in Figure 6, was constructed and utilized for all five cruises.

B. NAVIGATION

The R/V ACANIA's position was determined by the use of Loran augmented by either visual bearings or radar ranges. Loran is an electronic system utilizing a cathode ray tube to measure time intervals in microseconds between a pair of stations. One advantage of this system over others is in the speed in obtaining a position. A more complete explanation of the theory and operation of this equipment can be reviewed in either Dutton's Navigation and Piloting (1958) or the appropriate NAVSHIPS Technical Manual.

The accuracy of positioning obtained with Loran and the other methods mentioned was considered excellent, thus no navigational corrections were deemed necessary.

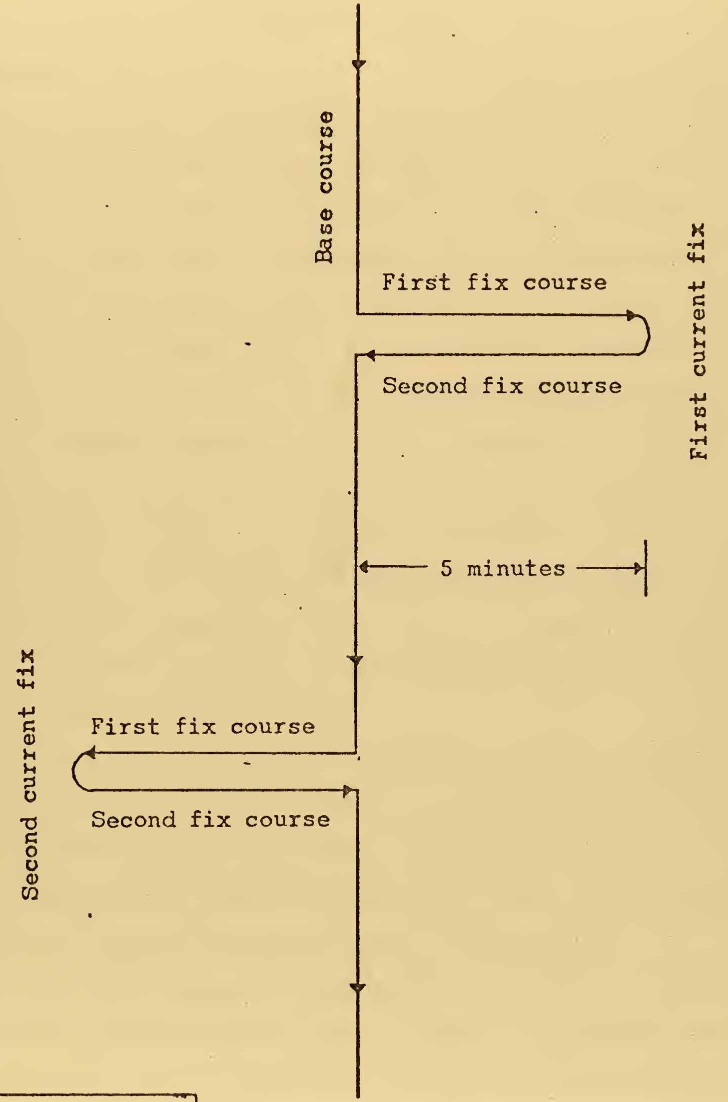


Figure 6. Cruise Plan Utilized

V. CRUISES AND RESULTS

A. INTRODUCTION

This section provides a description of each of the five cruises with regard to the surface current vectors, tide condition, the 10° C mean isothermal surface for November and December 1971, and the historical 12° C mean isothermal surface. The isotherm figures for November and December 1971 are taken from McClelland (1972) and the historical plots are taken from a study by Lammars (1971). All computations in determining current magnitude and direction were made using the IBM-360/67 computer. A copy of the computer program is included in the Appendix. The current vectors are plotted using the subroutines of the plotting package for the CALCOMP Model 765 with the NPS Computer. No attempt was made to scale these vectors to the actual magnitudes due to the requirement of all graphs having the dimensions of 6 x 9 inches. The current vectors of each cruise are plotted separately and then combined to show the circulation over the entire Bay (see Fig. 12).

Information pertaining to tides was obtained from the U. S. Coast and Geodetic Survey Tide Tables for the West Coast of North and South America (1971). This data was plotted along with the magnitude of the current vectors. Comments on the apparent influence of the tides on the observed surface current pattern are contained in Sec. VI-A, Conclusions.

McClelland (1972) during his investigation of the temperature patterns in Monterey Bay concluded that the entire Bay area was approximately 2°C colder than past years. In order to make any comparison between historical isothermal surfaces and those measurements made during November-December 1971, it was necessary to compare the present 10°C surfaces with the 12°C

surfaces. This was not entirely successful as pointed out by McClelland and readily seen by comparing any of the historical plots with its respective contemporary plot.

The current vectors determined by GEK data were superimposed on both the historical and contemporary plots in an attempt to compare the actual GEK determined current vectors with the direction of the current vectors inferred from the isothermal plots.

Lammer's plots represent data compiled from 1929 to 1968 while the plots of McClelland represent data taken weekly and averaged for the months studied. The various regions of highs and lows appearing on the 10°C and 12°C isothermal surfaces cannot be thought of as being fixed. The contours vary from day to day and also from year to year, therefore, the figures may be considered as useful indicators of "average conditions" only. It would be difficult at best to ascertain the reasons for the obvious decrepancies. It is sufficient to state that variations in temperature, salinity, and the influences of wind and the Davidson Current would all contribute to these differences.

B. CRUISES

1. Cruise No. 1

a. General

Two short cruises were conducted prior to Cruise 1 in order to check out equipment performance and the procedure for acquiring the necessary data. This proved necessary as several malfunctions of the recorder needed attention. However, the largest single impediment was corrected with the replacement of the three-prong plug leading from the recorder to the ships outlet by a conventional two-prong plug (see Sec. III-A).

Data collection began on 23 November 1971 with the acquisition of 18 current fixes. The current vector magnitude and direction are illustrated on Fig. 7a and are detailed in Table 1 and in the Appendix. Current magnitudes and tidal amplitudes are plotted in Fig. 7b. Reference to the tidal influence will be made later.

b. Analysis of Data

The first 18 current fixes were taken in the center portion of the Monterey Submarine Canyon using a base course of 270°(T)-090°(T). There were no particular reasons for picking these courses other than it was felt that most of the flow would be perpendicular to ship's head and that maximum coverage of the area would be obtained for the time available. It is seen that a majority of the velocity vectors have a northwesterly trend with an average magnitude of approximately 0.33 Knot (15.5 cm/sec).

Viewing Fig. 7c and 7d, the inferred currents are in a direction parallel to the isotherms. The plotted GEK current vectors in these two figures appear to cross the isotherms at nearly right angles and are thus perpendicular, instead of parallel to the directions of the

inferred currents. No reasonable explanation can be given for this phenomenon except that as mentioned in Sec. V-A the isothermal plots are derived from averaging data and an even general agreement would not necessarily be expected.

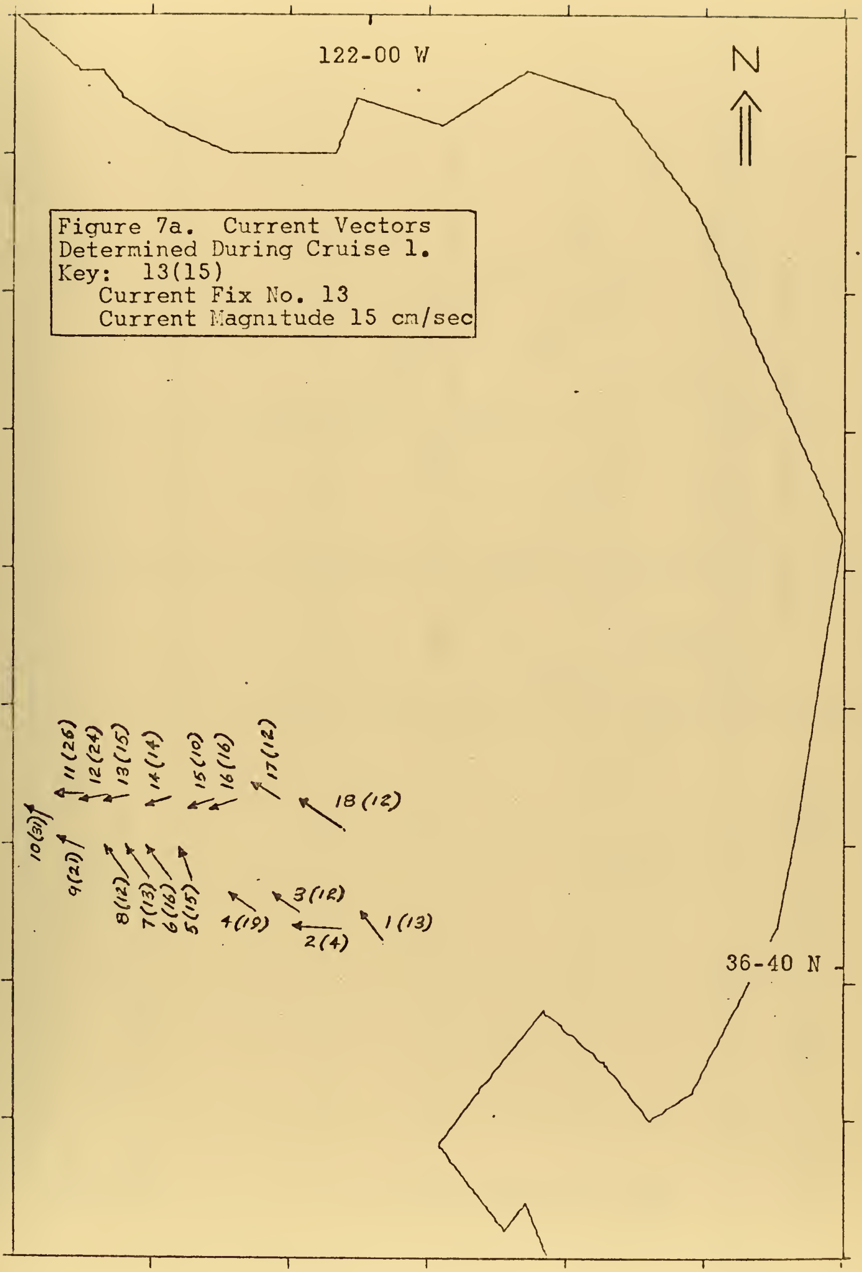


Figure 7a. Current Vectors Determined During Cruise 1.
Key: 13(15)
Current Fix No. 13
Current Magnitude 15 cm/sec

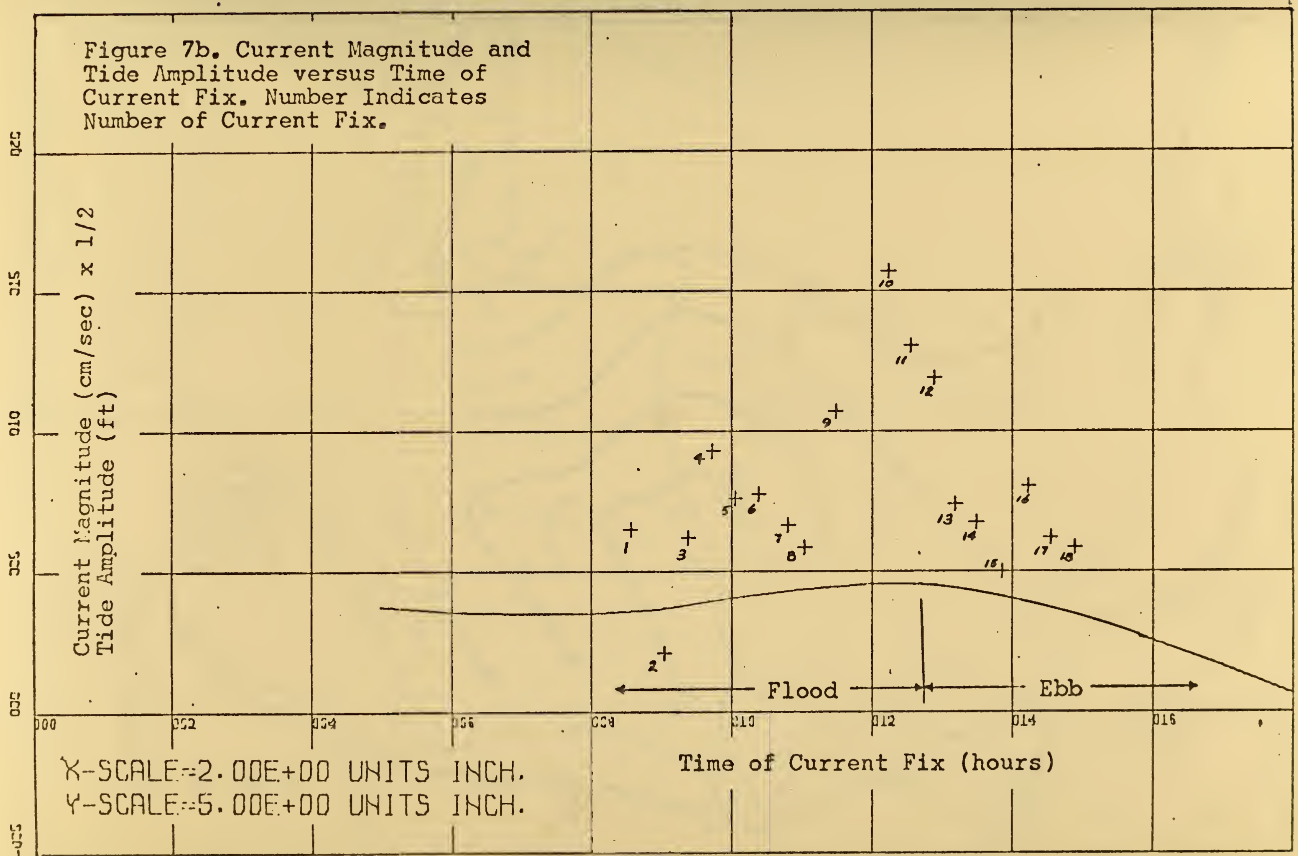


Figure 7b. Current Magnitude and Tide Amplitude versus Time of Current Fix. Number Indicates Number of Current Fix.

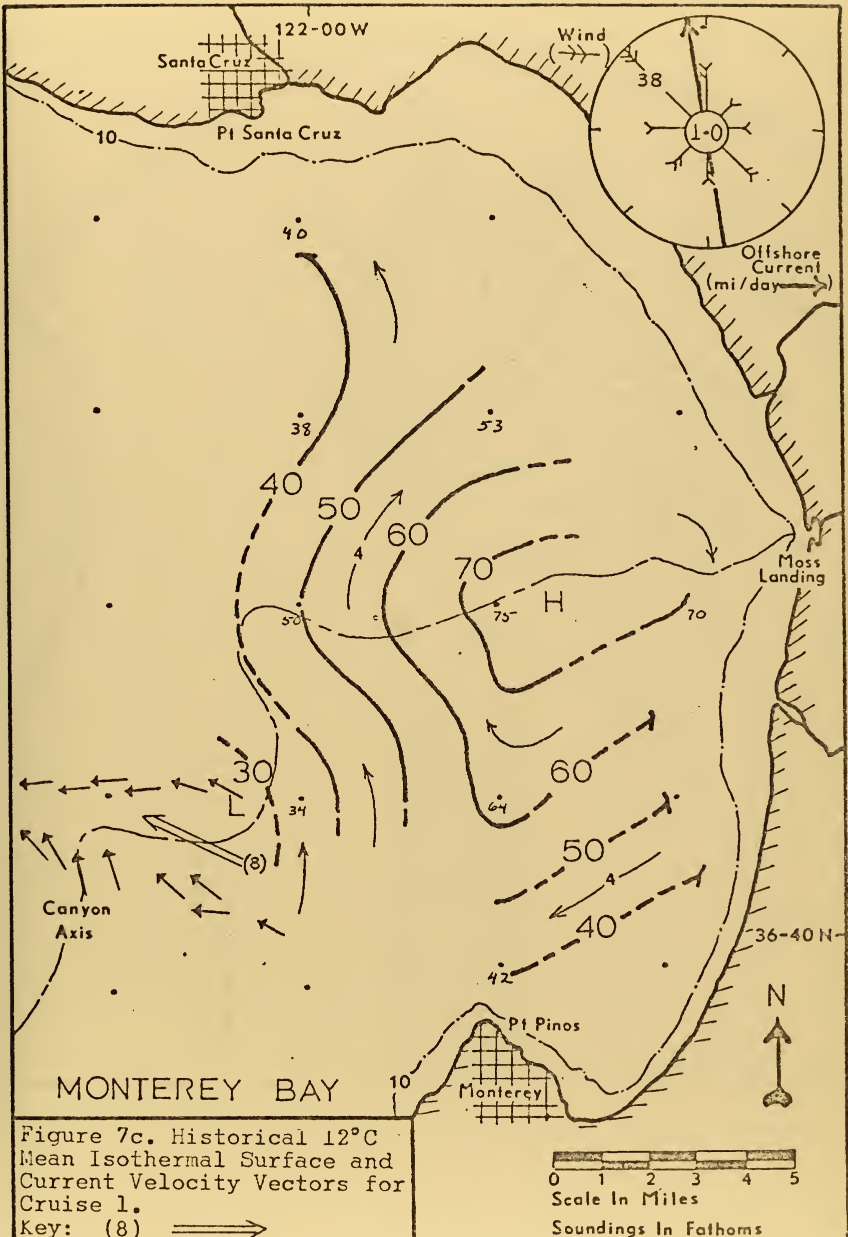


Figure 7c. Historical 12°C Mean Isothermal Surface and Current Velocity Vectors for Cruise 1.
Key: (8) ⟹ Average Velocity 8 mi/day.

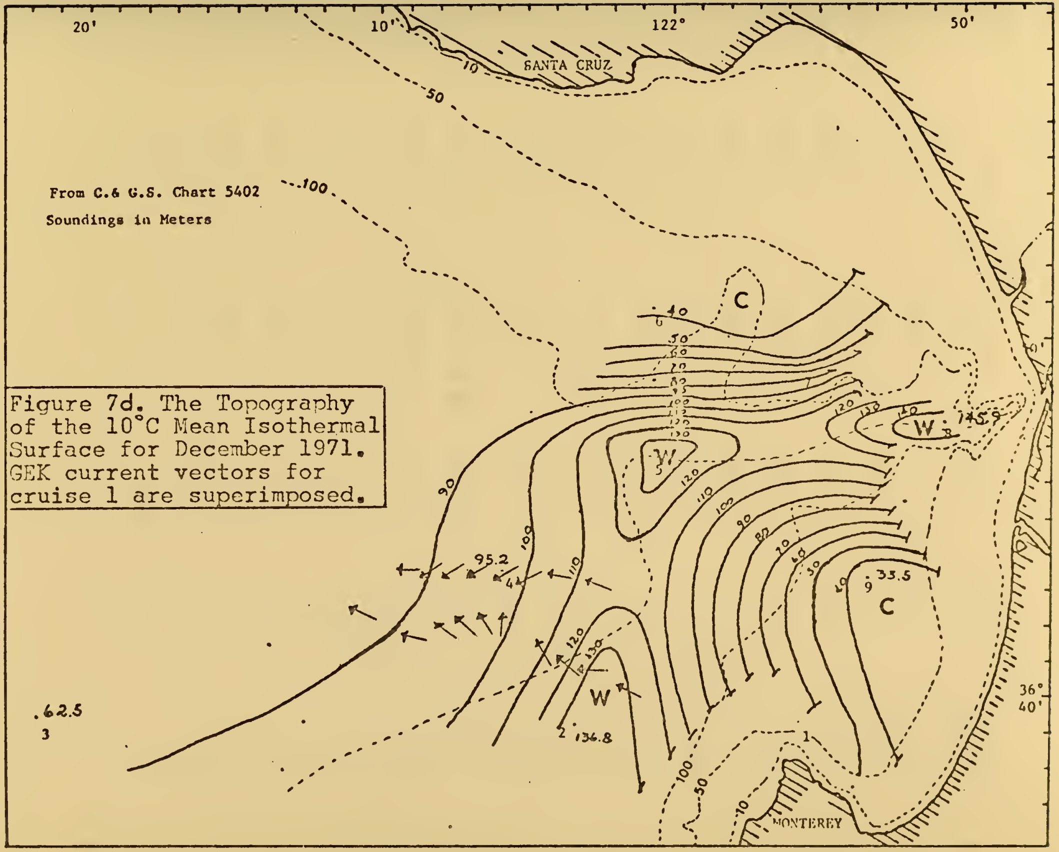


Figure 7d. The Topography of the 10°C Mean Isothermal Surface for December 1971. GEK current vectors for cruise 1 are superimposed.

TABLE Ia. CRUISE 1 CURRENT VECTOR SPECIFICATIONS

VECTOR NO.	LOCATION LATITUDE (N) (deg - min)	LONGITUDE (W) (deg - min)	DEPTH (fm)	CURRENT SPEED (cm/sec)	CURRENT DIRECTION (deg T)
1	36-40.0	122-01.0	230	13.1	292.4
2	36-40.5	122-02.5	350	4.3	273.2
3	36-40.6	122-03.0	600	12.5	310.4
4	36-40.7	122-04.0	800	18.7	324.3
5	36-41.0	122-05.7	1000	15.2	356.4
6	36-41.2	122-06.5	1100	15.7	356.5
7	36-41.5	122-07.0	800	13.4	337.1
8	36-41.6	122-07.5	600	11.8	319.9
9	36-41.6	122-08.7	525	21.4	282.8
10	36-42.2	122-10.0	500	31.5	281.3
11	36-43.2	122-08.8	620	26.1	272.1
12	36-43.2	122-08.0	700	23.9	252.6
13	36-43.2	122-07.7	900	14.9	253.3
14	36-43.4	122-06.3	900	13.5	259.9
15	36-43.4	122-05.3	900	10.1	250.7
16	36-43.3	122-04.5	700	16.1	256.4
17	36-43.2	122-03.1	600	12.5	287.7
18	36-43.1	122-02.2	500	11.7	291.4

TABLE Ib. CRUISE 1 ENVIRONMENTAL DATA

WEATHER

WIND	SWELL	SEA STATE	VISABILITY
NW 3-6 knots	3-4 ft	0	10 miles overcast

TIDE

TIME	HEIGHT	DESCRIPTION
0732	3.5 ft	HLW
1244	4.6 ft	HHW
2014	-0.3 ft	LLW

2. Cruise No. 2

a. General

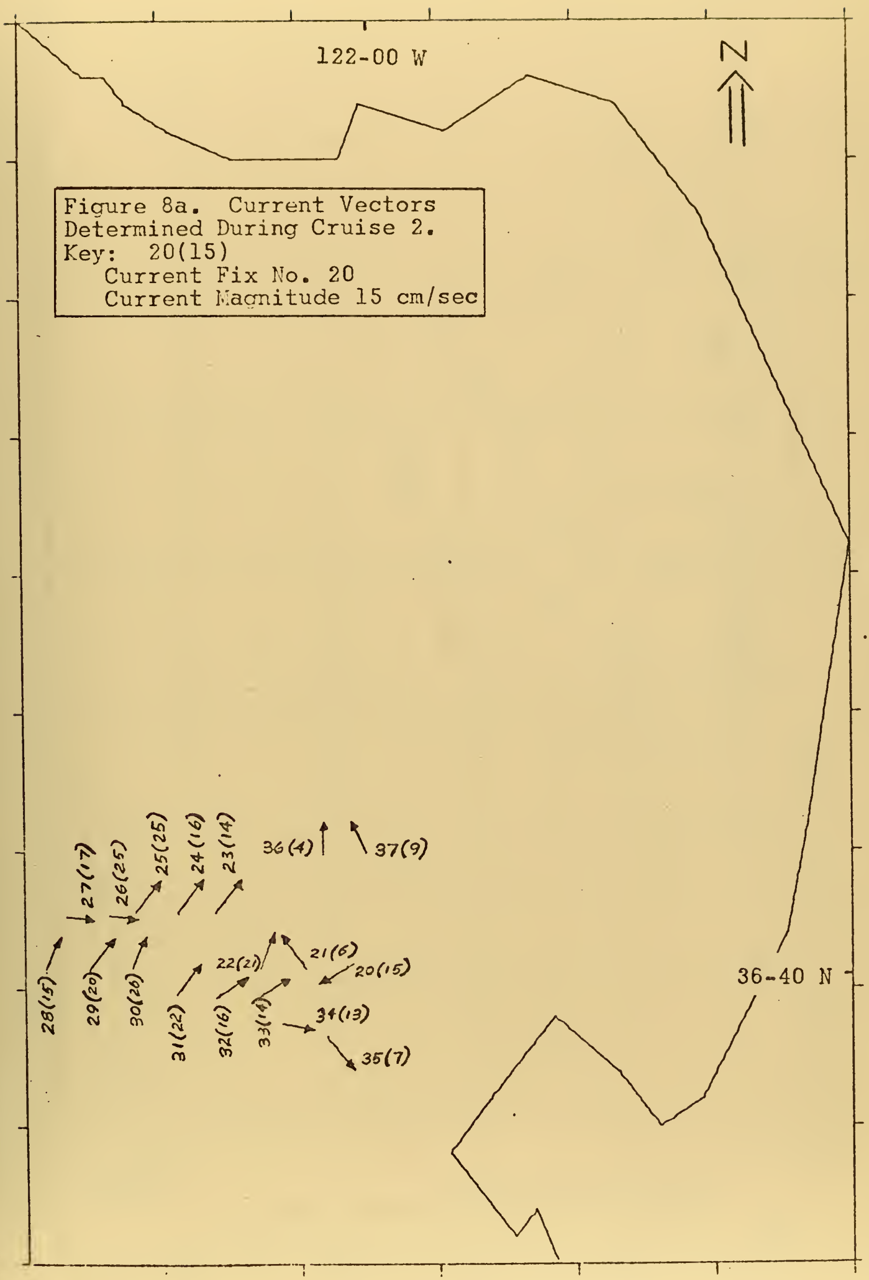
Eighteen current fixes were obtained on 20 December 1971. No mechanical problems were encountered during the cruise. The electrodes were soaked in sea water in a plastic bucket overnight in order to eliminate the two hour time lapse required for the electrodes to reach stabilization. Data was then recorded immediately upon reaching the operating area.

b. Analysis of Data

The second series of 18 current fixes were taken approximately one mile south of those of Cruise 1. The base course was once again 270°(T)-090°(T). The GEK current vectors generally had a northeast to east trend with an average magnitude of 0.30 knot (see Fig. 8a). Figure 8b is a plot of the current magnitudes and tidal amplitudes.

All the vectors were outside the area studied by Lammars as seen in Fig. 8c with the exception of vectors 36 and 37 which appear to conform to the historical pattern.

In Fig. 8d the GEK current vectors compare favorably with the current directions inferred from the 10°C isotherm pattern with the exception of vectors 26 and 27. It must be kept in mind that the isotherms are averaged values plotted for the entire month and can differ appreciably on a day to day basis. Lammars, McKay, and others have concluded that the current and temperature patterns are highly dependent on time and position, therefore, until a joint study envolving temperature, salinity, and current measurements is undertaken the results of all the partial studies will be less than fully satisfactory.


122-00 W
N
Figure 8a. Current Vectors
Determined During Cruise 2.
Key: 20(15)
Current Fix No. 20
Current Magnitude 15 cm/sec
36(4)
37(9)
27(17)
26(25)
25(25)
24(16)
23(14)
28(15)
29(20)
30(20)
31(22)
22(21)
21(6)
20(15)
32(16)
33(14)
34(13)
35(7)
36-40 N

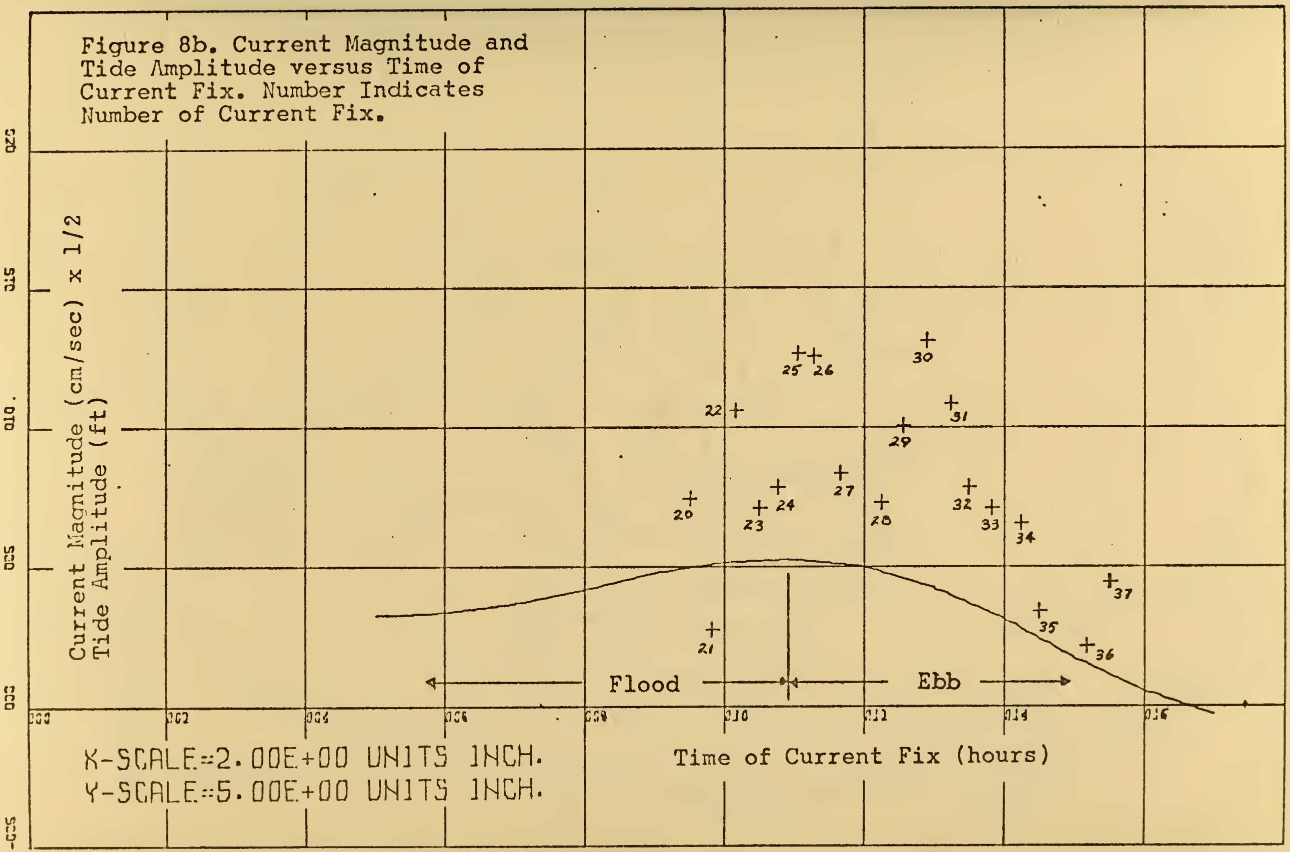


Figure 8b. Current Magnitude and Tide Amplitude versus Time of Current Fix. Number Indicates Number of Current Fix.

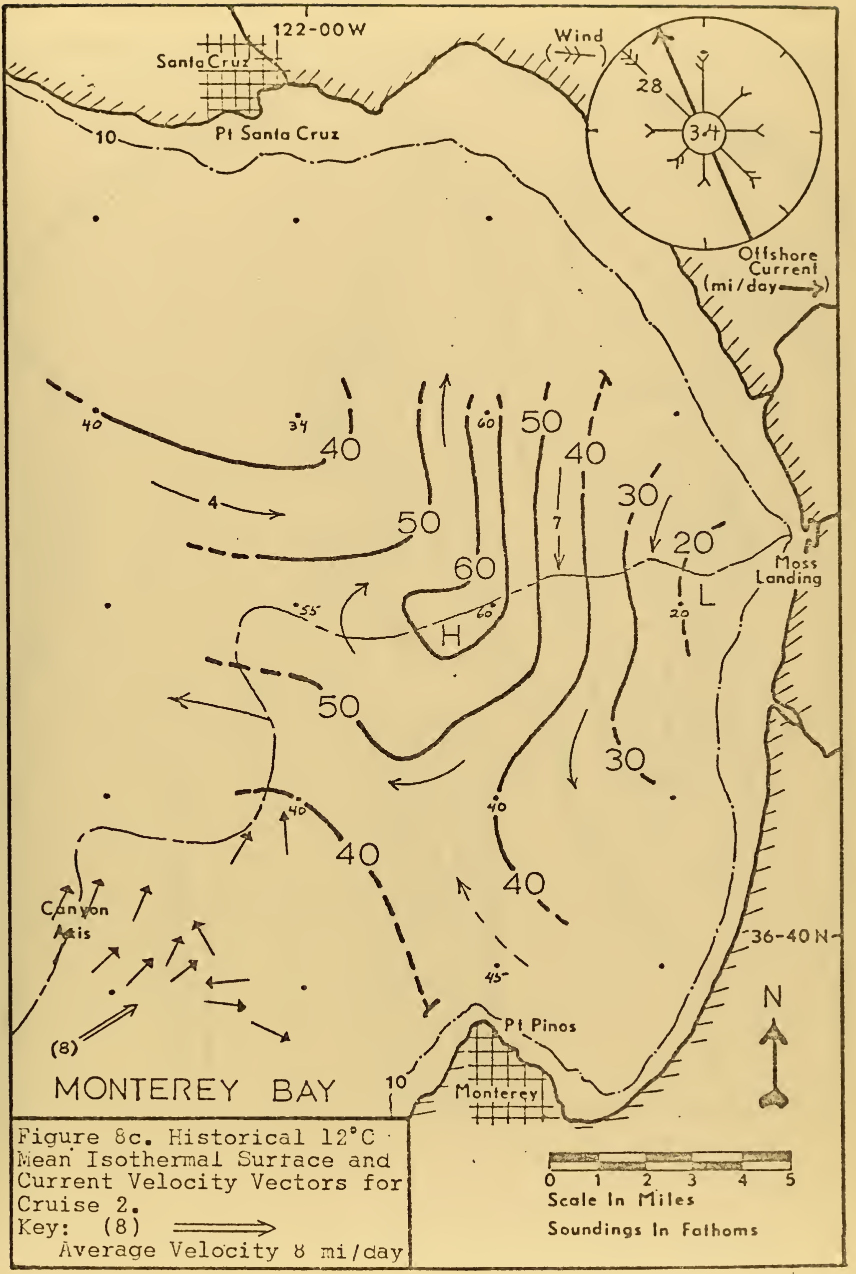


Figure 8c. Historical 12°C Mean Isothermal Surface and Current Velocity Vectors for Cruise 2.
Key: (8) ⟹ Average Velocity 8 mi/day

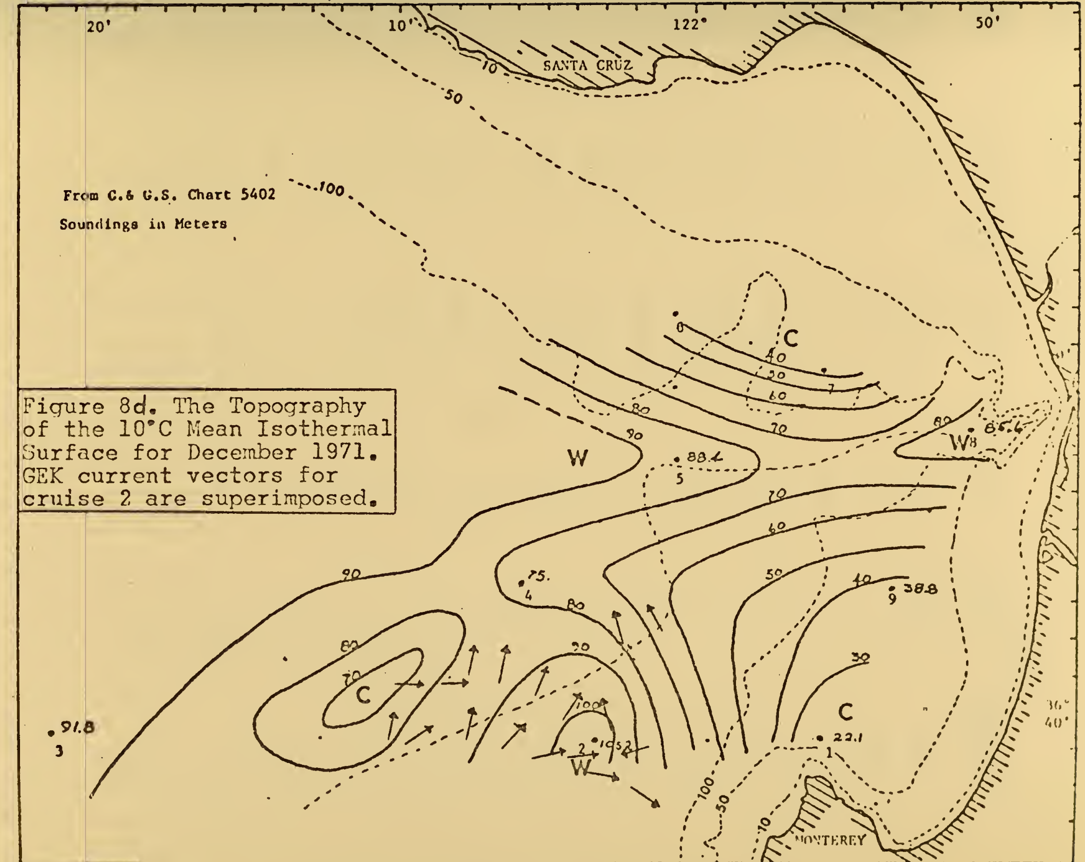


Figure 8d. The Topography of the 10°C Mean Isothermal Surface for December 1971. GEK current vectors for cruise 2 are superimposed.

TABLE IIa. CRUISE 2 CURRENT VICTOR SPECIFICATIONS

VECTOR NO.	LOCATION LATITUDE (N) (deg - min)	LOCATION LONGITUDE (W) (deg - min)	DEPTH (fm)	CURRENT SPEED (cm/sec)	CURRENT DIRECTION (deg T)
20	36-39.0	122-02.0	300	15.0	259.1
21	36-39.5	122-03.0	500	5.6	340.0
22	36-39.5	122-04.2	900	21.3	51.3
23	36-40.2	122-05.2	1000	14.3	68.6
24	36-40.2	122-06.4	700	15.7	61.1
25	36-40.5	122-07.5	800	25.3	59.6
26	36-40.5	122-08.4	650	25.2	93.2
27	36-40.7	122-09.4	550	16.7	96.5
28	36-39.2	122-10.0	700	14.6	13.1
29	36-39.4	122-08.8	700	20.2	25.6
30	36-39.4	122-07.5	950	26.2	35.4
31	36-39.2	122-06.4	950	21.8	53.9
32	36-38.8	122-05.2	800	15.8	74.3
33	36-38.8	122-04.0	800	14.2	90.9
34	36-38.5	122-03.3	600	13.2	115.6
35	36-38.0	122-02.0	200	6.9	123.7
36	36-41.8	122-02.2	900	4.4	12.5
37	36-42.2	133-01.0	700	8.9	334.8

TABLE IIb. CRUISE 2 ENVIRONMENTAL DATA

WEATHER

WIND	SWELL	SEA STATE	VISABILITY
N 4-6 knots	1-2 ft	0	6-10 miles fog-haze

TIDE

TIME	HEIGHT	DESCRIPTION
0520	3.3 ft	HLW
1056	5.3 ft	HHW
1832	-0.9 ft	LLW

3. <u>Cruise No. 3</u>

a. General

On 21 December 1971, 18 GEK current fixes were taken in Monterey Bay in a location seaward of Pt. Pinos and south of those of Cruise 2. No mechanical difficulties were encountered during the cruise.

b. Analysis of Data

The 18 current vectors were taken using a base course of 270°(T)-090°(T). The vectors themselves, as shown on Fig. 9a, exhibit in general a converging pattern toward the west-northwest.

No comparison of GEK current vectors and inferred currents was possible in this instance as the pattern of GEK current vectors were taken entirely outside the isthermal surfaces of Lammers and McClelland.

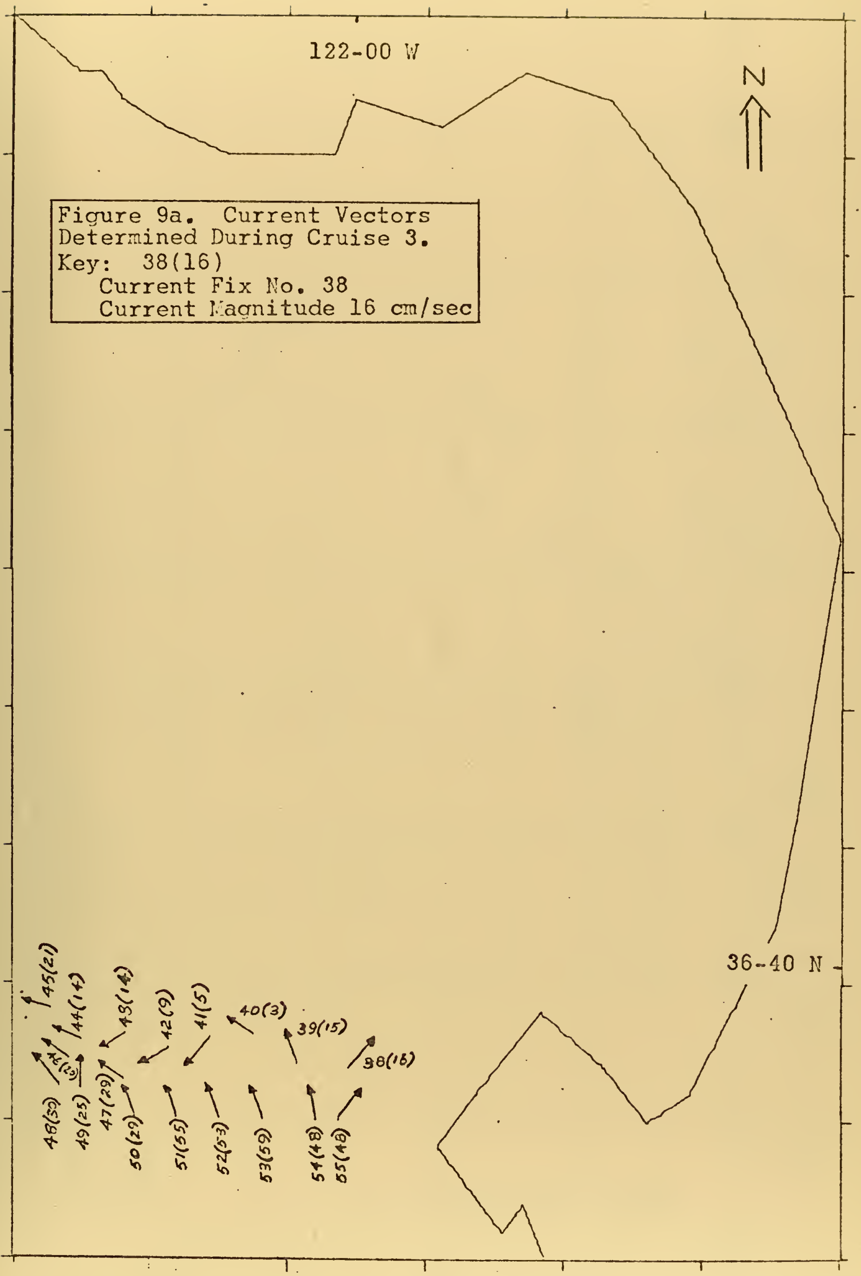


Figure 9a. Current Vectors Determined During Cruise 3.
Key: 38(16)
Current Fix No. 38
Current Magnitude 16 cm/sec

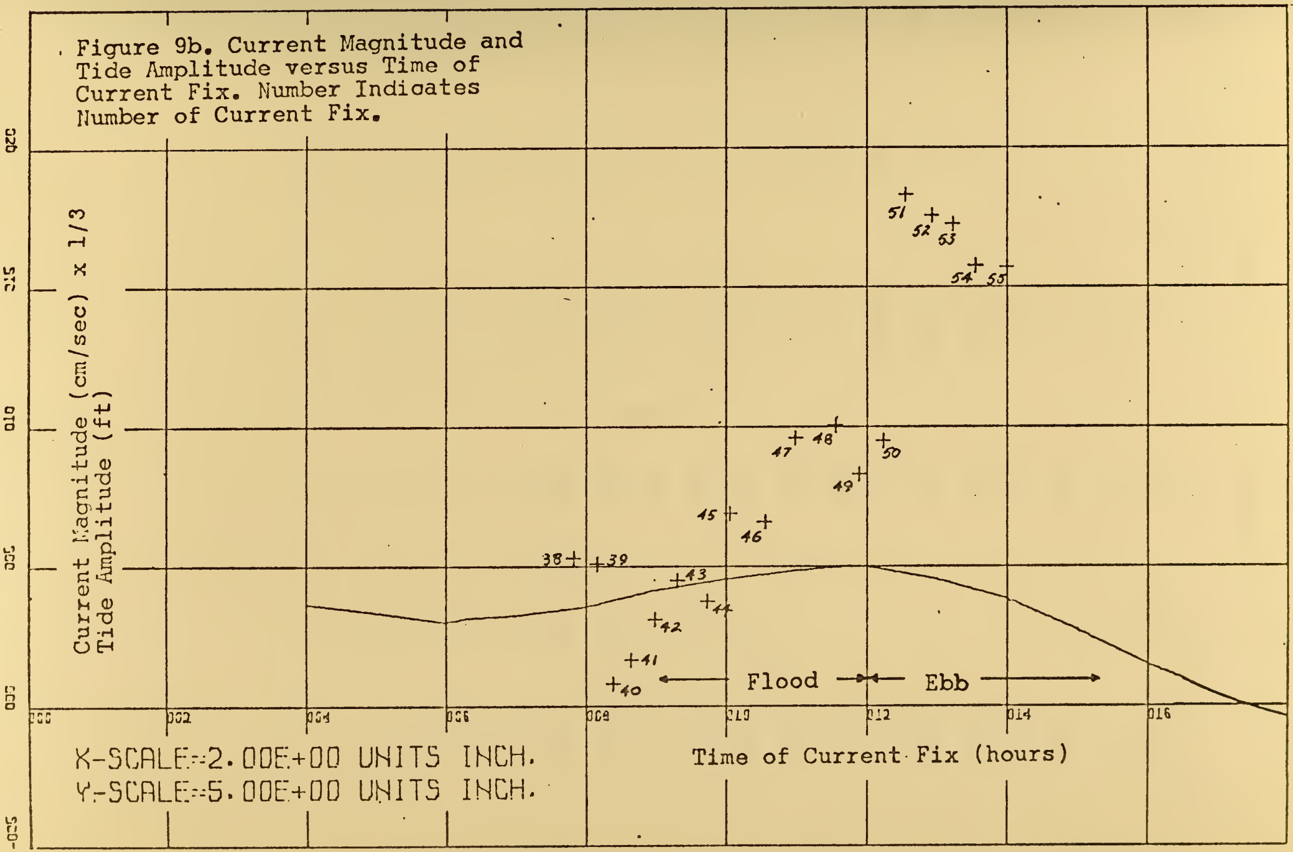


Figure 9b. Current Magnitude and Tide Amplitude versus Time of Current Fix. Number Indicates Number of Current Fix.

TABLE IIIa. CRUISE 3 CURRENT VECTOR SPECIFICATIONS

VECTOR NO.	LOCATION LATITUDE (N) (deg - min)	LOCATION LONGITUDE (W) (deg - min)	DEPTH (fm)	CURRENT SPEED (cm/sec)	CURRENT DIRECTION (deg T)
38	36-37.4	122-01.7	300	16.1	55.8
39	36-37.4	122-03.0	600	15.5	342.1
40	36-37.8	122-04.0	800	2.6	291.8
41	36-37.5	122-05.5	800	5.1	221.2
42	36-37.4	122-06.5	950	9.4	239.5
43	36-37.6	122-07.7	700	13.5	259.9
44	36-38.0	122-09.0	1000	14.3	268.1
45	36-38.2	122-10.0	850	20.7	285.9
46	36-37.2	122-09.2	1200	19.9	282.4
47	36-37.0	122-08.0	1050	28.9	279.5
48	36-36.3	122-09.6	1220	30.2	315.0
49	36-36.4	122.08.8	1050	24.9	342.3
50	36-36.0	122-07.7	1000	28.6	338.6
51	36-36.0	122-06.2	800	54.9	347.5
52	36-36.2	122-05.2	700	52.7	357.4
53	36-36.2	122-03.7	500	58.2	354.8
54	36-36.2	122-02.5	500	47.4	10.9
55	36-36.3	122-01.5	300	47.2	20.6

TABLE IIIb. CRUISE 3 ENVIRONMENTAL DATA

WEATHER

WIND	SWELL	SEA STATE	VISABILITY
NE 3-5 knots	1 ft	0	10 miles slight haze

TIDE

TIME	HEIGHT	DESCRIPTION
0620	3.2 ft	LHW
1144	5.0 ft	HHW
1914	-0.7 ft	LLW

4. Cruise No. 4

a. General

Twenty-one GEK current vector measurements were made on 28 December 1971. These vectors covered the largest area to date and involved a cruise of nearly 10 hours duration.

b. Analysis of Data

Sixteen of the 21 current vectors exhibit a general north-northwest direction while the other five vectors were directed in a south to southwest direction (see Fig. 10a). Figure 10b is the corresponding tide and current magnitude plot.

Vectors 76 and 56 are directly opposite from what could be expected from the 12°C isothermal surface plot, see Fig. 10c. The other vectors, however, could represent a logical extention of the isothermal surfaces.

Figure 10d shows that the GEK current vectors compare favorably with the 10°C mean isotherm in the shallower area, but as the water deepens the vector direction becomes mostly northward and the comparison becomes less favorable. A possible explanation is the presence of the Davidson Current which according to Lazanoff (1971) flows northward through the bay during this period of the year. It would seem logical that perhaps the magnitude of the current would be larger for vectors 60 - 70 if they were influenced by the Davidson Current, but this was not the case.

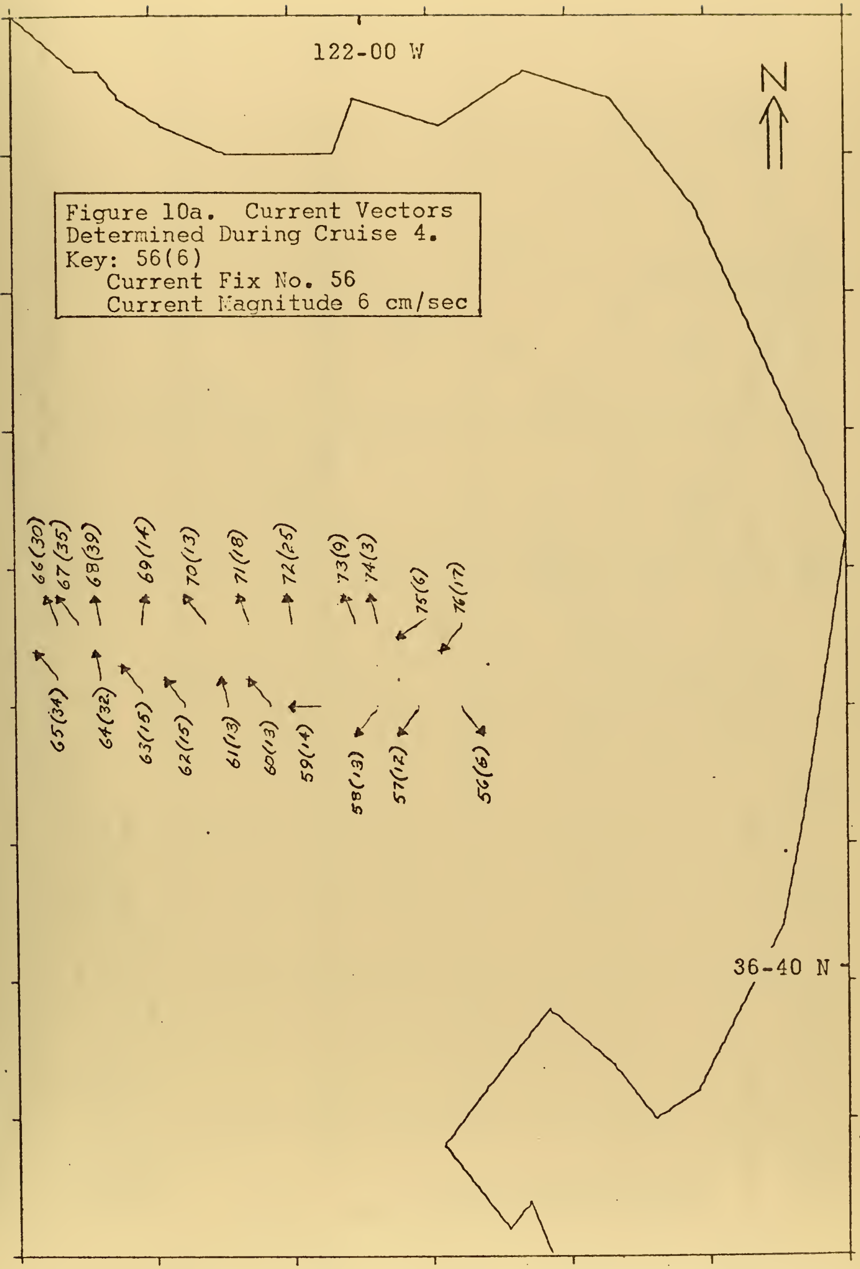


Figure 10a. Current Vectors Determined During Cruise 4.
Key: 56(6)
Current Fix No. 56
Current Magnitude 6 cm/sec

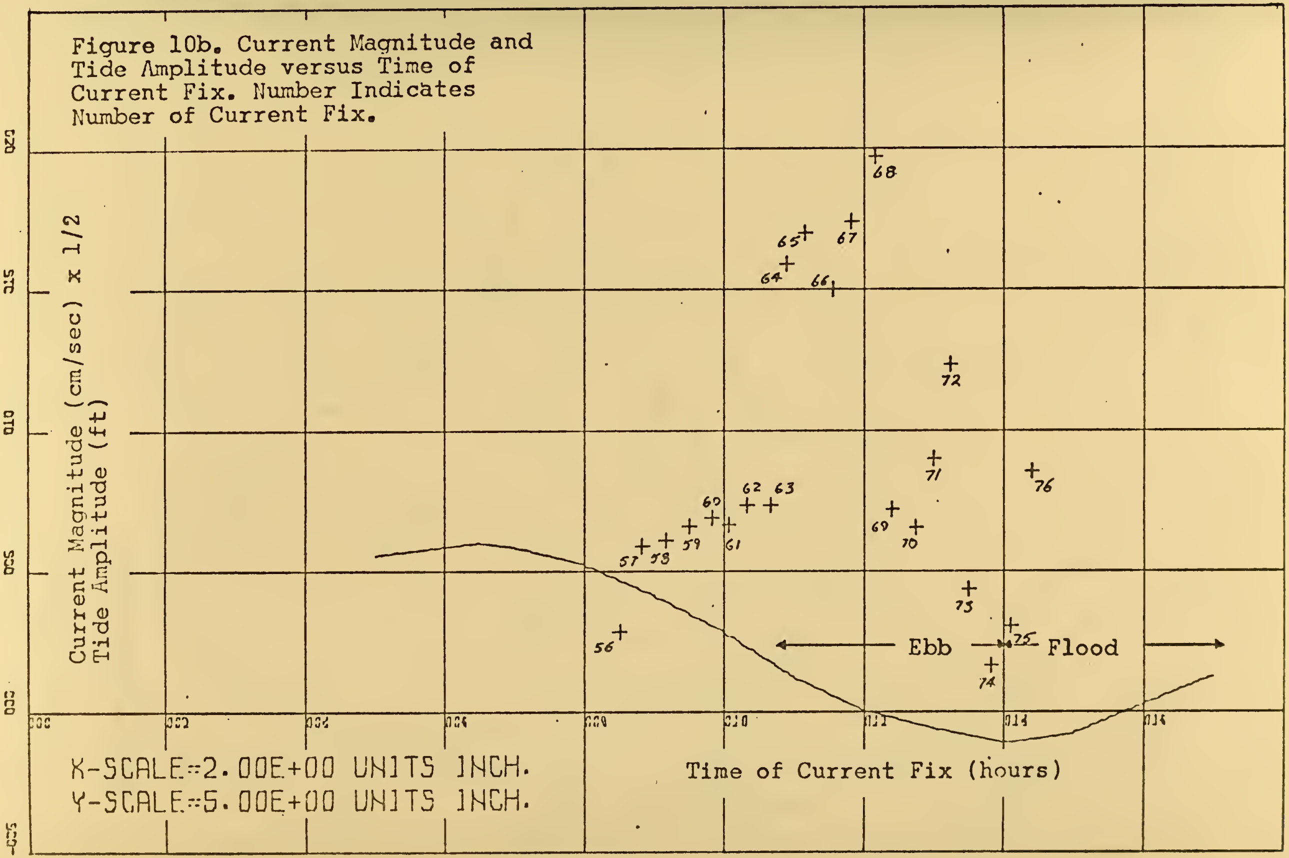


Figure 10b. Current Magnitude and Tide Amplitude versus Time of Current Fix. Number Indicates Number of Current Fix.

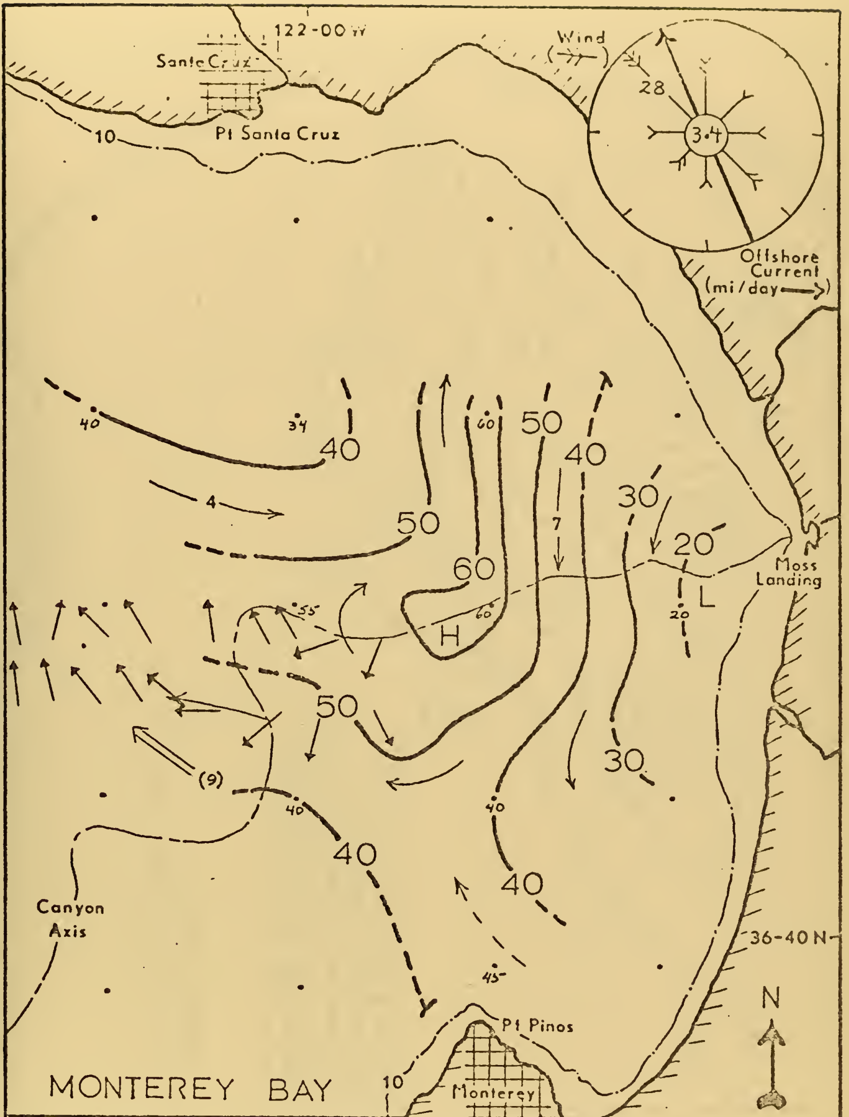


Figure 10c. Historical 12°C Mean Isothermal Surface and Current Velocity Vectors for Cruise 4.
Key: (9) ⟹
Average Velocity 9 mi/day

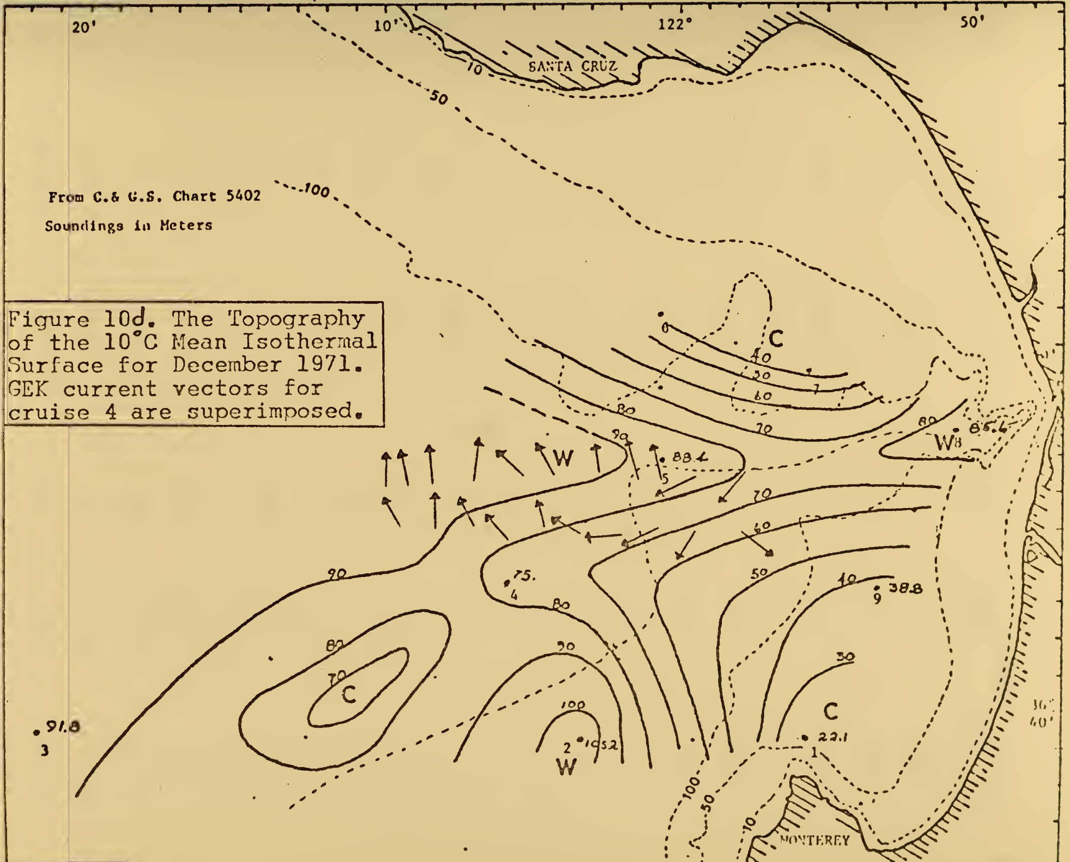


Figure 10d. The Topography of the 10°C Mean Isothermal Surface for December 1971. GEK current vectors for cruise 4 are superimposed.

TABLE IVa. CRUISE 4 CURRENT VECTOR SPECIFICATION

VECTOR NO.	LOCATION LATITUDE (N) (deg - min)	LOCATION LONGITUDE (W) (deg - min)	DEPTH (fm)	CURRENT SPEED (cm/sec)	CURRENT DIRECTION (deg T)
56	36-45.0	121-58.2	200	5.7	155.6
57	36-44.8	121-59.6	400	11.9	216.9
58	36-45.0	122-00.8	500	12.3	234.5
59	36-45.0	122-02.1	550	13.3	267.9
60	36-45.0	122-03.5	400	13.9	308.1
61	36-45.2	122-04.6	550	13.3	355.9
62	36-45.0	122-05.8	500	14.8	326.8
63	36-45.3	122-07.0	700	14.7	345.1
64	36-45.6	122-08.1	700	31.8	357.4
65	36-45.4	122-09.5	500	34.0	324.1
66	36-46.7	122-09.8	500	30.0	355.4
67	36-46.7	122-09.2	500	34.8	342.6
68	36-46.7	122-08.3	500	39.5	357.2
69	36-46.5	122-06.9	450	14.5	23.2
70	36-46.7	122-05.5	500	13.2	300.3
71	36-46.7	122-04.2	400	18.1	333.4
72	36-46.7	122-02.7	300	24.8	355.6
73	36-46.6	122-01.2	500	8.7	337.6
74	36-46.6	122-00.5	500	3.4	351.9
75	36-46.6	121-59.4	500	6.2	247.4
76	36-46.5	121-58.0	350	17.2	228.4

TABLE IVb. CRUISE 4 ENVIRONMENTAL DATA

WEATHER

WIND	SWELL	SEA STATE	VISABILITY
NE 3-6 ft	long NE 3-4 ft	1	clear

TIDE

TIME	HEIGHT	DESCRIPTION
0632	6.1 ft	HHW
1408	-1.1 ft	LLW
2056	3.9 ft	LHW

5. <u>Cruise No. 5</u>

a. General

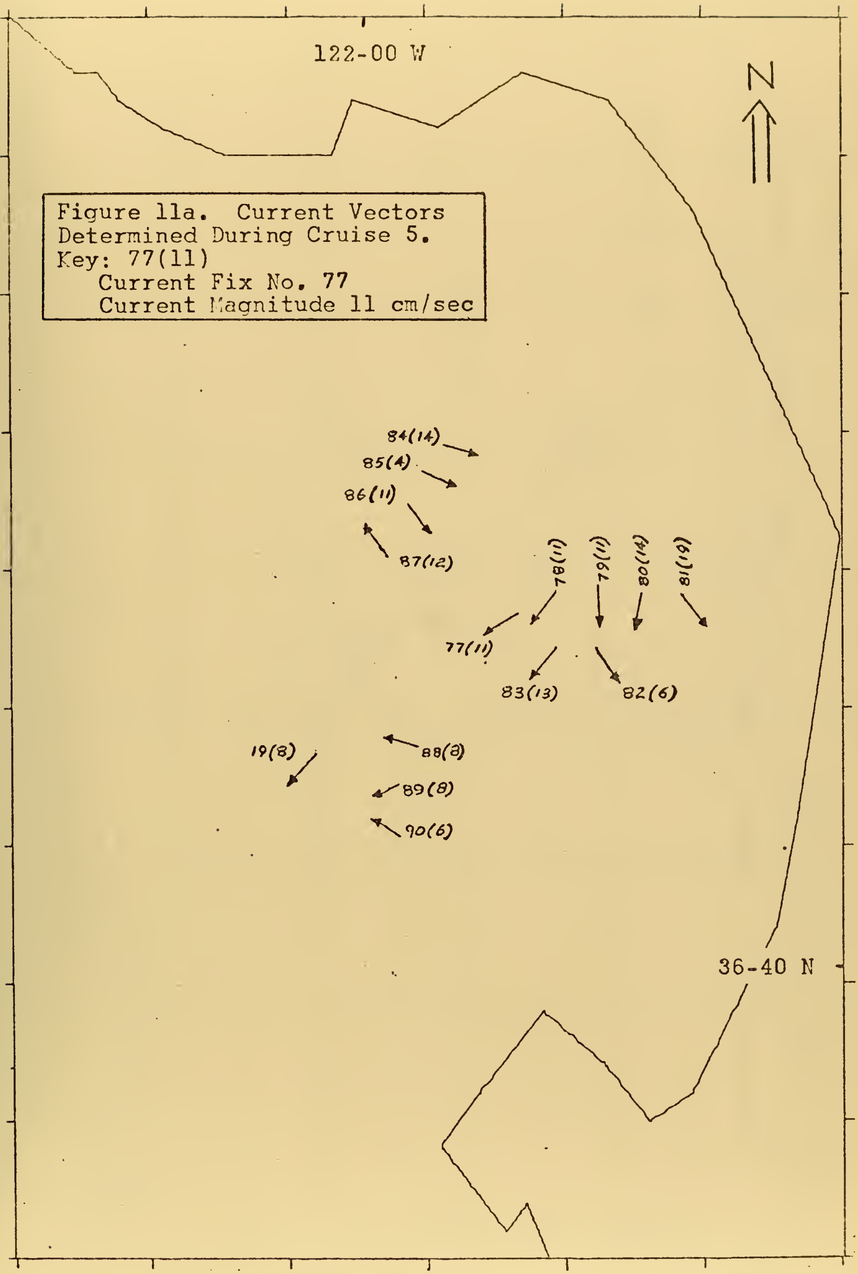
The final cruise in this investigation was made on December 29, 1971; the area around the head of the Monterey Bay Submarine Canyon had been left for last.

b. Analysis of Data

Various base courses were utilized as the stations were scattered over the northeastern section of the canyon. The results are shown in Fig. 11a and 11b.

In this case the vectors were entirely within the isothermal surfaces plotted by Lammars and conformed nearly exactly to what could have been predicted with the exception of vectors 19, 89, and 90 see Fig. 11c.

In regard to Fig. 11d, the best match between inferred and GEK currents was achieved during this cruise. Nearly all the vectors conformed to the contemporary plot. No clear reason can be given for this occurrence since conditions were exactly the same as the earlier cruises with the possible exception of the bottom topography of the canyon and the proximity of land. The vectors were taken in a location closer to land where the effects of the Davidson Current would have been minimal.


122-00 W
N
Figure 11a. Current Vectors
Determined During Cruise 5.
Key: 77(11)
Current Fix No. 77
Current Magnitude 11 cm/sec
84(14)
85(4)
86(11)
87(12)
78(11)
79(11)
80(14)
81(19)
77(11)
83(13)
82(6)
19(8)
88(8)
89(8)
90(6)
36-40 N

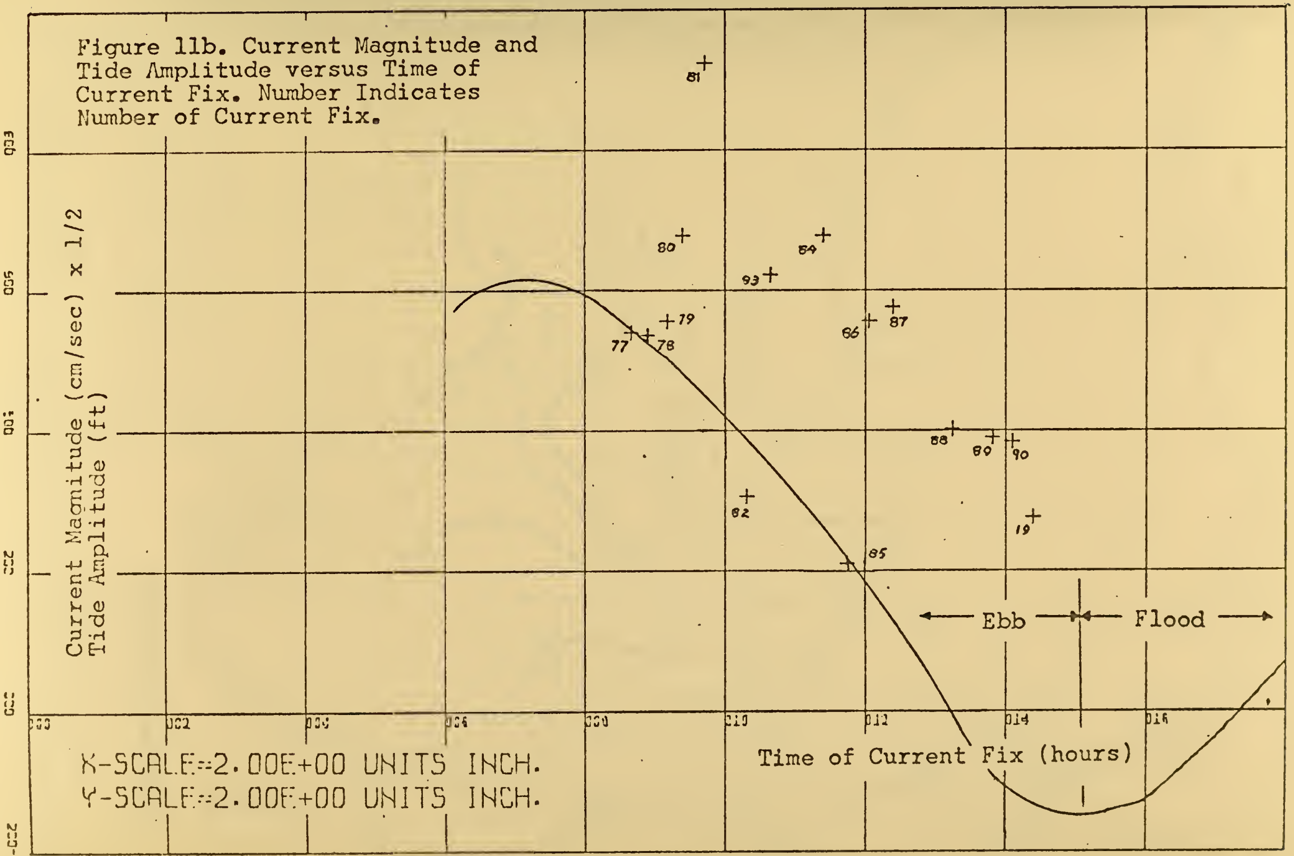


Figure 11b. Current Magnitude and Tide Amplitude versus Time of Current Fix. Number Indicates Number of Current Fix.

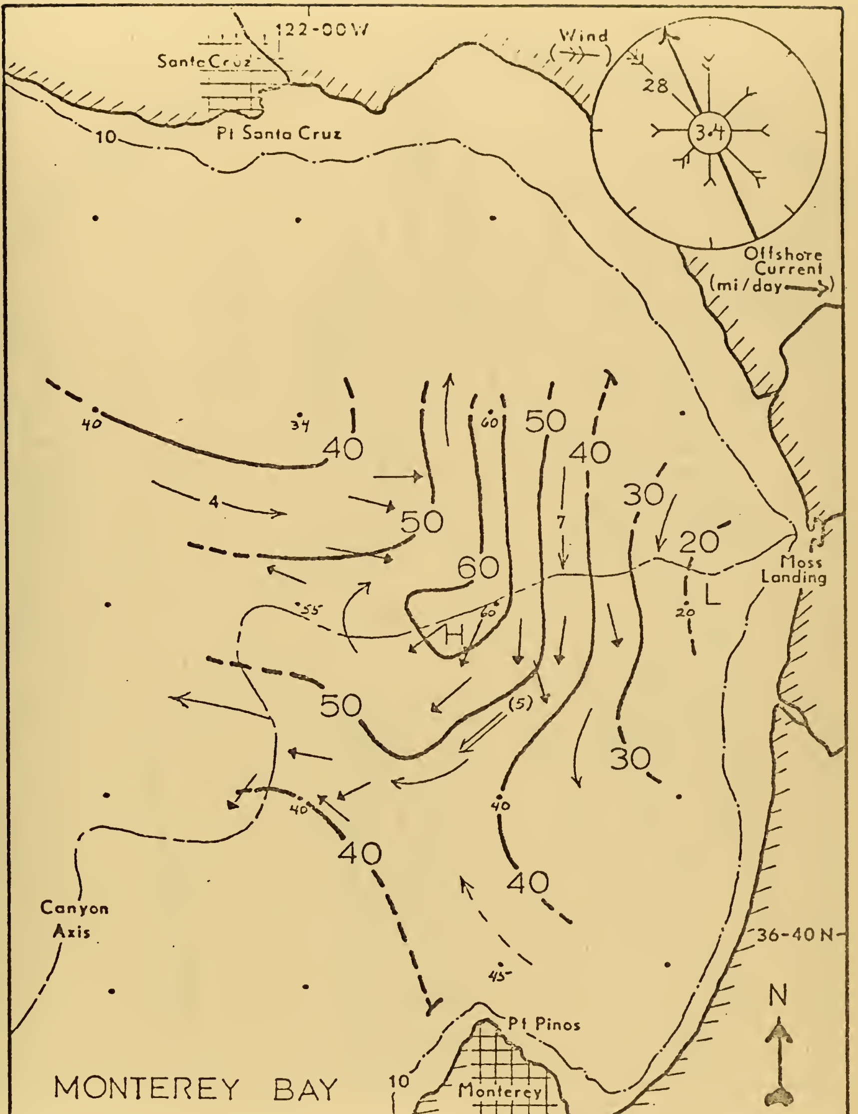


Figure 11c. Historical 12°C Mean Isothermal Surface and Current Velocity Vectors for Cruise 5.
Key: (5) ⟹ Average Velocity 5 mi/day

0 1 2 3 4 5
Scale In Miles
Soundings In Fathoms

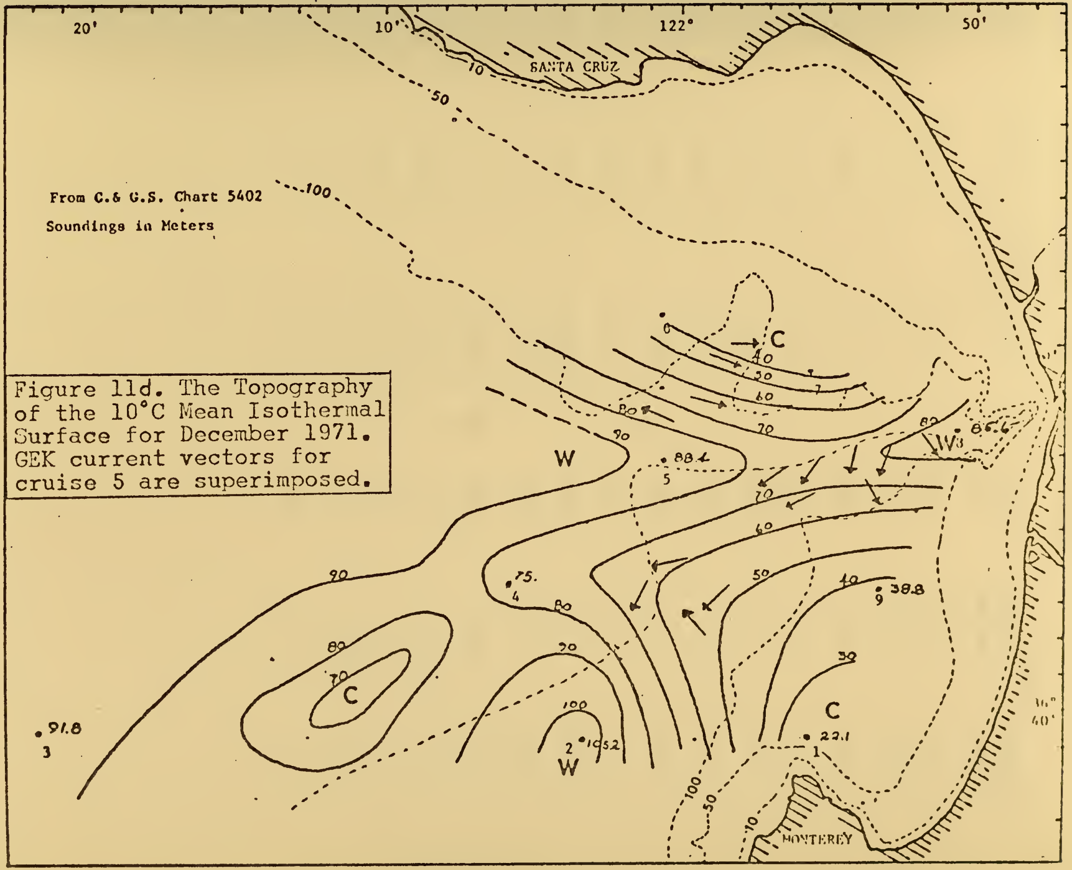


Figure 11d. The Topography of the 10°C Mean Isothermal Surface for December 1971. GEK current vectors for cruise 5 are superimposed.

TABLE Va. CRUISE 5 CURRENT VECTOR SPECIFICATIONS

VECTOR NO.	LOCATION LATITUDE (N) (deg - min)	LOCATION LONGITUDE (W) (deg - min)	DEPTH (fm)	CURRENT SPEED (cm/sec)	CURRENT DIRECTION (deg T)
77	36-46.8	121-56.3	300	10.8	231.2
78	36-47.0	121-55.2	300	10.8	218.6
79	36-47.3	121-54.0	300	11.2	182.3
80	36-47.3	121-52.9	200	13.6	194.8
81	36-47.6	121-51.7	200	18.5	147.4
82	36-46.4	121-53.7	200	6.2	157.4
83	36-46.2	121-55.4	200	12.5	229.6
84	36-50.3	121-58.0	200	13.6	98.5
85	36-49.7	121-58.7	200	4.3	108.4
86	36-48.7	121-59.6	300	11.2	122.7
87	36-48.0	122-00.1	300	11.6	324.5
88	36-44.0	121-59.3	400	7.8	284.1
89	36-43.0	121-59.5	350	7.7	227.5
90	36-42.5	121-59.5	200	5.5	329.1
91	36-43.5	122-01.5	600	8.1	208.1

TABLE Vb. CRUISE 5 ENVIRONMENTAL DATA

WEATHER

WIND	SWELL	SEA STATE	VISABILITY
calm	long NW 3-4 ft	1	clear

TIDE

TIME	HEIGHT	DESCRIPTION
0720	6.2 ft	HHW
1502	-1.5 ft	LLW
2150	4.1 ft	LHW

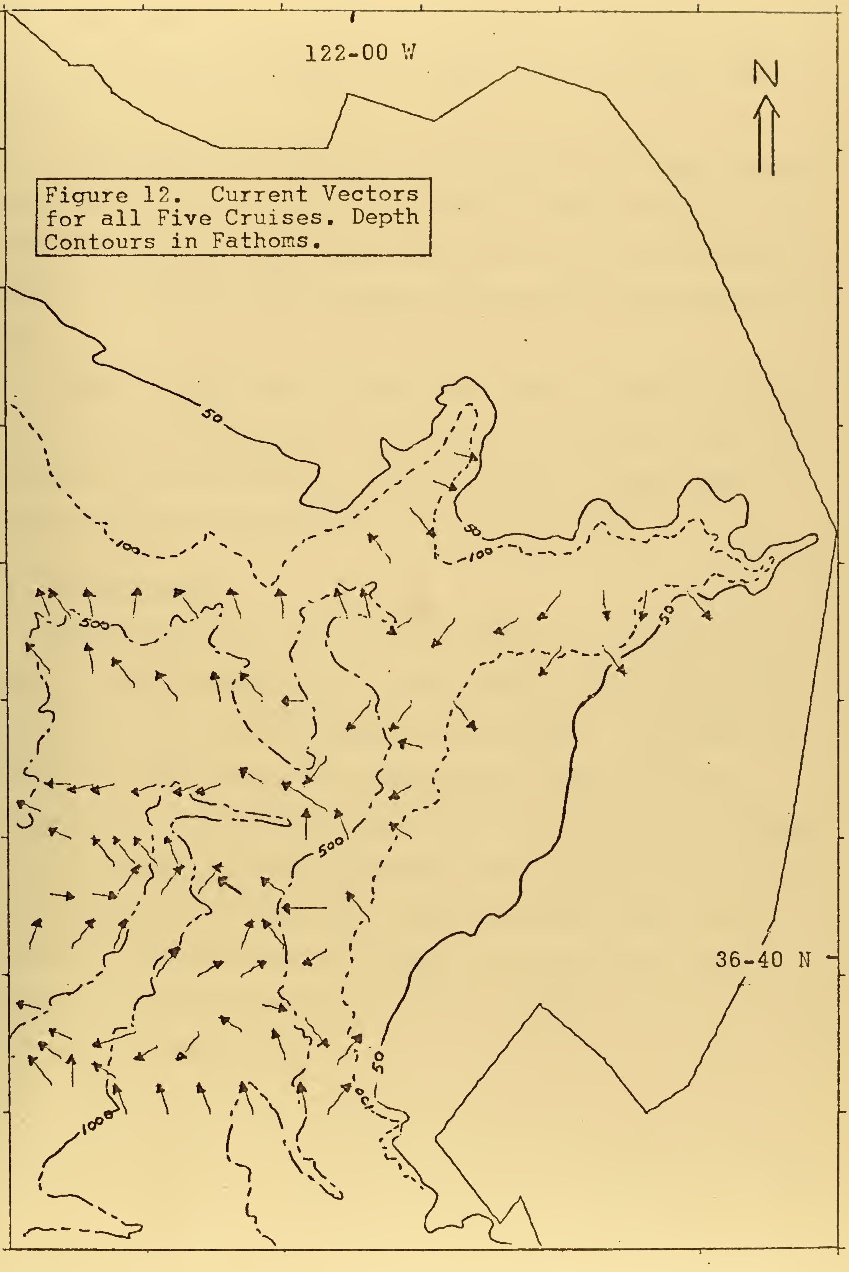
VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

From Fig. 12, the composite plot of GEK current vectors for all five cruises, it is apparent that the current pattern in Monterey Bay is highly dependent on time and position.

Tidal influence on the GEK current vectors was investigated but with little success due to the lack of references which would fully explain the tidal current in the Bay. Normally, if tidal current data is not directly available for a location of interest, the current predictions have to be interpolated between known stations as shown in the USCGS Tidal Current Tables. The nearest stations to Monterey Bay were Pt. Pinos and a point two miles south of Pt. Santa Cruz. However, the tables advise that the tidal currents are too weak and variable to be predicted at these locations. Lazanoff (1971) did a study in Monterey Bay on tidal currents using the Hansen Numerical Model and concluded that the principal driving force of the circulation in the bay was the oceanic currents and not the tides and winds. Monterey Bay tides probably act like those in open oceans or large embayments in that they are elliptical, moving in this case in a clock-wise direction with maximum speeds occurring midway between turning points and minimum at high and low waters. Lazanoff concluded that the tidal currents should be on the order of 0.1 knot (5 cm/sec), but due to some inherent problems in his model he was not actually able to verify this fact.

In light of the above limited information concerning the character of the tidal currents it is concluded that the overall surface circulation



122-00 W
N
Figure 12. Current Vectors for all Five Cruises. Depth Contours in Fathoms.
50
100
500
50
100
500
50
100
1000
36-40 N

of the bay varies from day to day as evidenced by the many distinct circulation patterns established for each of the five cruises as seen in Fig. 12.

Comparison with the 10°C mean isotherms and the 12°C mean isotherms was interesting but not really very successful since conditions in the Monterey Bay appear to vary daily causing some of the current vectors plotted to conform to the isotherms while others were perpendicular to them.

Finally, an exact value for the K-factor was not known which implies that the current magnitude may be in error by as much as 5%. With the placement of current meters in the Bay it would be a simple matter to calculate values for the K-factor as a function of depth.

B. RECOMMENDATIONS

The GEK would best be employed in Monterey Bay as part of a joint study involving the placement of current meters at various depths and the taking of salinity and temperature measurements. The K-factor as a function of depth could then be determined and a valid comparison between GEK, current meter data, and inferred currents might be obtained.

Von Arx (1962) describes how weights may be suspended from the GEK cable to determine the approximate depth at which the current data is gathered. If these weights were varied, a velocity profile could be calculated which would undoubtedly provide a valuable insight into the circulation of Monterey Bay.

APPENDIX A

The following pages contain:

(a) A listing of the computer program used to reduce the GEK traces the GEK traces to current velocities and

(b) a complete listing of the raw input data and final current velocities.

COMPUTER PROGRAM TO PROCESS GEK DATA FROM MONTEREY BAY

```
      WRITE(6,3000)
 3000 FORMAT('1',40X,'GEK DATA FROM MONTEREY BAY NOV-DEC 1971')
      WRITE(6,1000)
 1000 FORMAT('0','NO',5X,'BASE',5X,'FIX',6X,'SFIX',4X,'SBASE',5X,'ZERO',
     12X,'BASE AVG',2X,'FIX AVG',4X,'MAG',6X,'DIR',5X,'CORMAG',2X,'MAG(K
     1TS)',1X,'CORDIR')
      J=0
    2 READ(5,501)X,Y,W,Z,W1,Z1,X1
  501 FORMAT(7F10.0)
      J=J+1
      WW=0.5*(W+W1)
      XX=-WW+0.5*(X+X1)
      YY=ABS(XX)
      IF(XX-YY)10,20,20
   10 IF(Y-180.0)12,12,13
   12 A=Y+180.0
      GO TO 21
   13 A=Y-180.0
      GO TO 21
   20 A=Y
      GO TO 21
   21 B=ABS(W-WW)
      IF(W-W1)50,60,60
   50 C=Z1
      GO TO 61
   60 C=Z
      GO TO 61
   61 D=SQRT(YY**2+B**2)
      E=B/YY
      E1=ATAN(E)
      E2=E1*57.29577
      A1=A+90.0
      IF(A1-C)30,40,30
   30 F=A-E2
      GO TO 41
   40 F=A+E2
      GO TO 41
C     APPLING MAGNETIC CORRECTION
C     STD IS .400, LOCAL AREA CORR IS .437
C     VERTICAL MAGNETIC CORR FROM HO 1702 IS .437/.400 = .913
   41 F1=ABS(F)
```

```
      D1=0.913*D**1.04
      D2=0.0194*D1
      F2=F1+90.0
      IF(F2-360.0)70,70,80
   70 F3=F2
      GO TO 300
   80 F3=F2-360.0
      GO TO 300
  300 WRITE(6,2000)J,X,W,W1,X1,WW,YY,B,D,F1,D1,D2,F3
 2000 FORMAT('0',I2,12F9.2)
      IF(J-90)3,4,4
    3 GO TO 2
    4 STOP
      END
```

GEK DATA FROM MONTEREY BAY NOV-DEC 1971

NO	BASE	FIX	SFIX	SBASE	ZERO	BASE AVG	FIX AVG	MAG	DIR	CORMAG	MAG(KTS)	CORDIR
1	-5.00	-18.00	7.50	5.00	-5.25	5.25	12.75	13.79	202.38	13.09	0.25	292.38
2	3.50	15.00	6.00	18.00	10.50	0.25	4.50	4.51	183.18	4.28	0.08	273.18
3	18.00	3.00	23.00	25.00	13.00	8.50	10.00	13.12	220.36	12.46	0.24	310.36
4	-5.00	-10.00	-33.00	-6.00	-21.50	16.00	11.50	19.70	234.29	18.71	0.36	324.29
5	-6.00	-24.00	-22.00	-8.00	-23.00	16.00	1.00	16.03	266.42	15.22	0.30	356.42
6	-8.00	-23.00	-25.00	-7.00	-24.00	16.50	1.00	16.53	266.53	15.70	0.30	356.53
7	-7.00	-23.00	-12.00	-2.00	-17.50	13.00	5.50	14.12	247.07	13.40	0.26	337.07
8	-2.00	-11.00	-27.00	-17.00	-19.00	9.50	8.00	12.42	229.90	11.79	0.23	319.90
9	-17.00	-42.00	2.00	-13.00	-20.00	5.00	22.00	22.56	192.80	21.42	0.42	282.80
10	-5.00	-30.00	35.00	-3.00	2.50	6.50	32.50	33.14	191.31	31.47	0.61	281.31
11	-3.00	30.00	-25.00	6.00	2.50	1.00	27.50	27.52	182.08	26.13	0.51	272.08
12	6.00	-25.00	23.00	7.00	-1.00	7.50	24.00	25.14	162.65	23.88	0.46	252.65
13	7.00	20.00	-10.00	12.00	5.00	4.50	15.00	15.66	163.30	14.87	0.29	253.30
14	12.00	-3.00	25.00	15.00	11.00	2.50	14.00	14.22	169.88	13.50	0.26	259.88
15	15.00	18.00	-2.00	8.00	8.00	3.50	10.00	10.59	160.71	10.06	0.20	250.71
16	8.00	-15.00	18.00	3.00	1.50	4.00	16.50	16.98	166.37	16.12	0.31	256.37
17	3.00	23.00	-2.00	10.00	10.50	4.00	12.50	13.12	197.74	12.46	0.24	287.74
18	10.00	5.00	28.00	14.00	16.50	4.50	11.50	12.35	201.37	11.73	0.23	291.37
19	-35.00	-59.00	-44.00	-60.00	-51.50	4.00	7.50	8.50	118.07	8.07	0.16	208.07
20	2.00	19.00	-12.00	-1.00	3.50	3.00	15.50	15.79	169.05	14.99	0.29	259.05
21	-1.00	-3.00	1.00	10.00	-1.00	5.50	2.00	5.85	250.02	5.56	0.11	340.02
22	10.00	-25.00	10.00	3.00	-7.50	14.00	17.50	22.41	321.34	21.28	0.41	51.34
23	3.00	18.00	-10.00	16.00	4.00	5.50	14.00	15.04	338.55	14.28	0.28	68.55
24	16.00	-7.00	22.00	15.00	7.50	8.00	14.50	16.56	331.11	15.72	0.31	61.11
25	10.00	18.00	-28.00	7.00	-5.00	13.50	23.00	26.67	329.59	25.32	0.49	59.59
26	7.00	-18.00	35.00	7.00	8.50	1.50	26.50	26.54	3.24	25.20	0.49	93.24

GEK DATA FROM MONTEREY BAY NOV-DEC 1971

NO	BASE	FIX	SFIX	SBASE	ZERO	BASE AVG	FIX AVG	MAG	DIR	CORMAG	MAG(KTS)	CORDIR
27	7.00	25.00	-10.00	4.00	7.50	2.00	17.50	17.61	6.52	16.72	0.32	96.52
28	-6.00	6.00	13.00	-5.00	9.50	15.00	3.50	15.40	283.13	14.63	0.28	13.13
29	-5.00	12.00	-7.00	-28.00	2.50	19.00	9.50	21.24	296.56	20.17	0.39	26.56
30	-28.00	-20.00	12.00	-25.00	-4.00	22.50	16.00	27.61	305.42	26.22	0.51	35.42
31	-25.00	12.00	-25.00	-15.00	-6.50	13.50	18.50	22.90	323.88	21.75	0.42	53.88
32	-15.00	-20.00	12.00	-2.00	-4.00	4.50	16.00	16.62	344.29	15.78	0.31	74.29
33	-2.00	15.00	-15.00	2.50	0.0	0.25	15.00	15.00	0.95	14.24	0.28	90.95
34	2.00	-10.00	15.00	15.00	2.50	6.00	12.50	13.87	25.64	13.17	0.26	115.64
35	14.00	6.00	-6.00	-6.00	0.0	4.00	6.00	7.21	33.69	6.85	0.13	123.69
36	10.00	12.00	10.00	3.00	11.00	4.50	1.00	4.61	282.53	4.38	0.08	12.53
37	3.00	15.00	7.00	2.00	11.00	8.50	4.00	9.39	244.80	8.92	0.17	334.80
38	-7.00	5.00	-23.00	8.00	-9.00	9.50	14.00	16.92	325.84	16.06	0.31	55.84
39	8.00	-8.00	-18.00	-3.00	-13.00	15.50	5.00	16.29	252.12	15.46	0.30	342.12
40	-3.00	-10.00	-5.00	-10.00	-7.50	1.00	2.50	2.69	201.80	2.56	0.05	291.80
41	-10.00	-5.00	-12.00	-15.00	-8.50	4.00	3.50	5.32	131.19	5.05	0.10	221.19
42	-15.00	-17.00	0.0	-12.00	-8.50	5.00	8.50	9.86	149.53	9.36	0.18	239.53
43	-12.00	3.00	-25.00	-15.00	-11.00	2.50	14.00	14.22	169.88	13.50	0.26	259.88
44	-15.00	-27.00	3.00	-10.00	-12.00	0.50	15.00	15.01	178.09	14.25	0.28	268.09
45	-10.00	5.00	-37.00	-10.00	-16.00	6.00	21.00	21.84	195.95	20.74	0.40	285.95
46	-24.00	-37.00	4.00	-18.00	-16.50	4.50	20.50	20.99	192.38	19.93	0.39	282.38
47	-16.00	12.00	-48.00	-30.00	-18.00	5.00	30.00	30.41	189.46	28.88	0.56	279.46
48	-36.00	-3.00	-48.00	-60.00	-25.50	22.50	22.50	31.82	225.00	30.21	0.59	315.00
49	-60.00	-27.00	-43.00	-60.00	-35.00	25.00	8.00	26.25	252.26	24.92	0.48	342.26
50	-60.00	-52.00	-30.00	-78.00	-41.00	28.00	11.00	30.08	248.55	28.56	0.55	338.55
51	-78.00	-8.00	-33.00	-76.00	-20.50	56.50	12.50	57.87	257.52	54.95	1.07	347.52
52	-76.00	-18.00	-23.00	-76.00	-20.50	55.50	2.50	55.56	267.42	52.75	1.02	357.42

GEK DATA FROM MONTEREY BAY NOV-DEC 1971

NO	BASE	FIX	SFIX	SBASE	ZERO	BASE AVG	FIX AVG	MAG	DIR	CORMAG	MAG(KTS)	CORDIR
53	-40.00	7.00	18.00	-57.00	12.50	61.00	5.50	61.25	264.85	58.16	1.13	354.85
54	-57.00	-9.00	10.00	-40.00	0.50	49.00	9.50	49.91	280.97	47.39	0.92	10.97
55	-40.00	-10.00	25.00	-38.00	7.50	46.50	17.50	49.68	290.62	47.18	0.92	20.62
56	-2.00	-18.00	-23.00	-50.00	-20.50	5.50	2.50	6.04	65.56	5.74	0.11	155.56
57	-50.00	-40.00	-55.00	-65.00	-47.50	10.00	7.50	12.50	126.87	11.87	0.23	216.87
58	-65.00	-73.00	-52.00	-75.00	-62.50	7.50	10.50	12.90	144.46	12.25	0.24	234.46
59	-75.00	-83.00	-55.00	-64.00	-69.00	0.50	14.00	14.01	177.95	13.30	0.26	267.95
60	-63.00	-64.00	-87.00	-70.00	-75.50	9.00	11.50	14.60	218.05	13.87	0.27	308.05
61	-70.00	-85.00	-83.00	-70.00	-84.00	14.00	1.00	14.04	265.91	13.33	0.26	355.91
62	-70.00	-73.00	-90.00	-67.00	-81.50	13.00	8.50	15.53	236.82	14.75	0.29	326.82
63	-67.00	-80.00	-72.00	-55.00	-76.00	15.00	4.00	15.52	255.07	14.74	0.29	345.07
64	-55.00	-82.00	-85.00	-45.00	-83.50	33.50	1.50	33.53	267.44	31.84	0.62	357.44
65	-45.00	-95.00	-53.00	-45.00	-74.00	29.00	21.00	35.81	234.09	34.00	0.66	324.09
66	-95.00	-57.00	-52.00	-77.00	-54.50	31:50	2.50	31.60	265.46	30.00	0.58	355.46
67	-77.00	-40.00	-62.00	-95.00	-51.00	35.00	11.00	36.69	252.55	34.84	0.68	342.55
68	-95.00	-48.00	-44.00	-80.00	-46.00	41.50	2.00	41.55	267.24	39.45	0.77	357.24
69	-80.00	-62.00	-50.00	-60.00	-56.00	14.00	6.00	15.23	293.20	14.46	0.28	23.20
70	-60.00	-61.00	-37.00	-52.00	-49.00	7.00	12.00	13.89	210.26	13.19	0.26	300.26
71	-52.00	-33.00	-50.00	-65.00	-41.50	17.00	8.50	19.01	243.43	18.05	0.35	333.43
72	-65.00	-37.00	-33.00	-57.00	-35.00	26.00	2.00	26.08	265.60	24.76	0.48	355.60
73	-57.00	-38.00	-45.00	-43.00	-41.50	8.50	3.50	9.19	247.62	8.73	0.17	337.62
74	-43.00	-35.00	-34.00	-33.00	-34.50	3.50	0.50	3.54	261.87	3.36	0.07	351.87
75	-32.00	-25.00	-37.00	-25.00	-31.00	2.50	6.00	6.50	157.38	6.17	0.12	247.38
76	-25.00	-42.00	-15.00	-8.00	-28.50	12.00	13.50	18.06	138.37	17.15	0.33	228.37
77	-45.00	-63.00	-43.00	-50.00	-53.00	5.50	10.00	11.41	141.19	10.84	0.21	231.19
78	-50.00	-50.00	-67.00	-52.00	-58.50	7.50	8.50	11.34	128.58	10.76	0.21	218.58

GEK DATA FROM MONTEREY BAY NOV-DEC 1971

NO	BASE	FIX	SFIX	SBASE	ZERO	BASE AVG	FIX AVG	MAG	DIR	CORMAG	MAG(KTS)	CORDIR
79	-50.00	-63.00	-58.00	-48.00	-60.50	11.50	2.50	11.77	92.26	11.17	0.22	182.26
80	-48.00	-55.00	-67.00	-48.00	-61.00	13.00	6.00	14.32	104.78	13.60	0.26	194.78
81	-48.00	-57.00	-72.00	-45.00	-64.50	18.00	7.50	19.50	57.38	18.52	0.36	147.38
82	-60.00	-58.00	-63.00	-73.00	-60.50	6.00	2.50	6.50	67.38	6.17	0.12	157.38
83	-73.00	-60.00	-80.00	-84.00	-70.00	8.50	10.00	13.12	139.64	12.46	0.24	229.64
84	-75.00	-52.00	-75.00	-69.00	-63.50	8.50	11.50	14.30	8.53	13.58	0.26	98.53
85	-69.00	-68.00	-60.00	-63.00	-64.00	2.00	4.00	4.47	18.43	4.25	0.08	108.43
86	-63.00	-50.00	-73.00	-65.00	-61.50	2.50	11.50	11.77	32.74	11.17	0.22	122.74
87	-63.00	-78.00	-74.00	-65.00	-76.00	12.00	2.00	12.17	234.46	11.55	0.22	324.46
88	-43.00	-54.00	-58.00	-53.00	-56.00	8.00	2.00	8.25	194.04	7.83	0.15	284.04
89	-53.00	-51.00	-62.00	-48.00	-56.50	6.00	5.50	8.14	137.49	7.73	0.15	227.49
90	-48.00	-55.00	-45.00	-46.00	-50.00	3.00	5.00	5.83	239.04	5.54	0.11	329.04

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13. ABSTRACT

Utilizing the geomagnetic electrokinetograph (GEK), surface currents in Monterey Bay were determined for five distinct cruises, each in a different portion of the bay, during the period November to December 1971. These cruises, using the Naval Postgraduate School (NPS) research vessel R/V Acania, yielded a total of 90 current speeds ranging from a low of 2.56 cm/sec to a high of 58.16 cm/sec. The direction of the current vectors were compared with currents inferred from the 10°C and 12°C mean isothermal surfaces. The isothermal surface data used was both of a historical and synoptic nature, the latter being obtained during the November-December 1971 time frame.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Crrents in Monterey Canyon						
GK						
Gomagnetic Electrokinetograph						
Srface Currents						

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